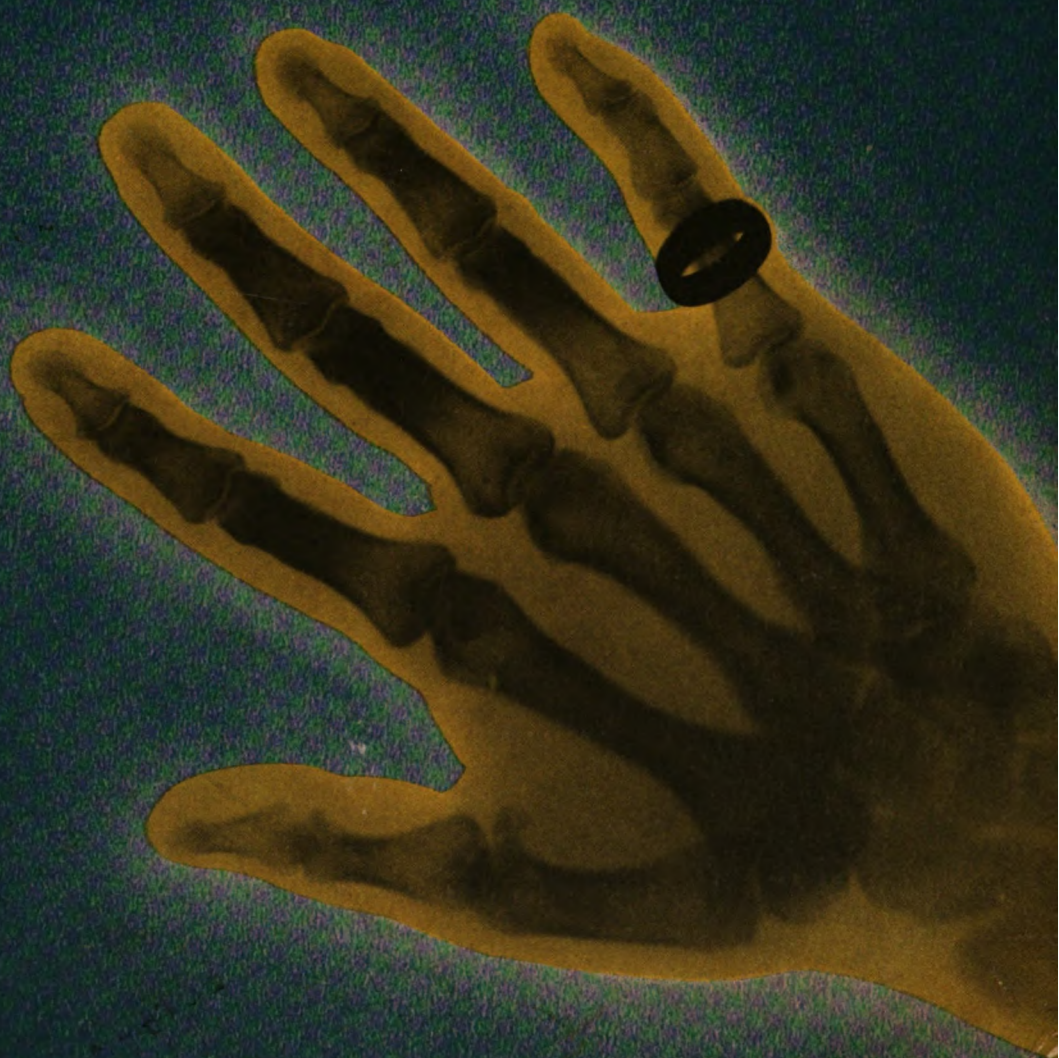


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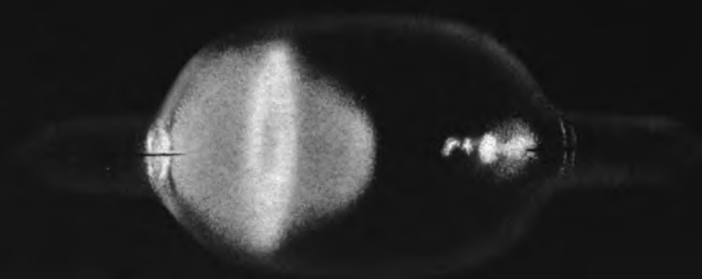


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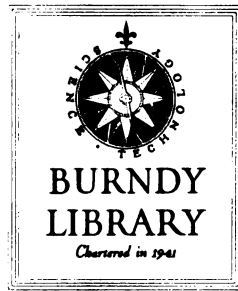
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The
NEW RAYS
of
PROFESSOR RÖNTGEN

by
BERN DIBNER



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PUBLICATION NO. 20

“When a law of nature, hitherto hidden, suddenly emerges from the surrounding fog, when the key, long sought after, to a mechanical combination is found, when the missing link takes its place in a chain of thought, there is then the elation of spiritual victory for the discoverer which by itself alone richly rewards him and lifts him for a brief moment on to a higher plane.”

—Röntgen, quoting Siemens, 1893

The radiograph of the hand on the cover was made in Philadelphia in December 1896, the first year of the discovery of X-rays. All the radiographs used in this monograph were made in this period and are from original sources in the Burndy Library.

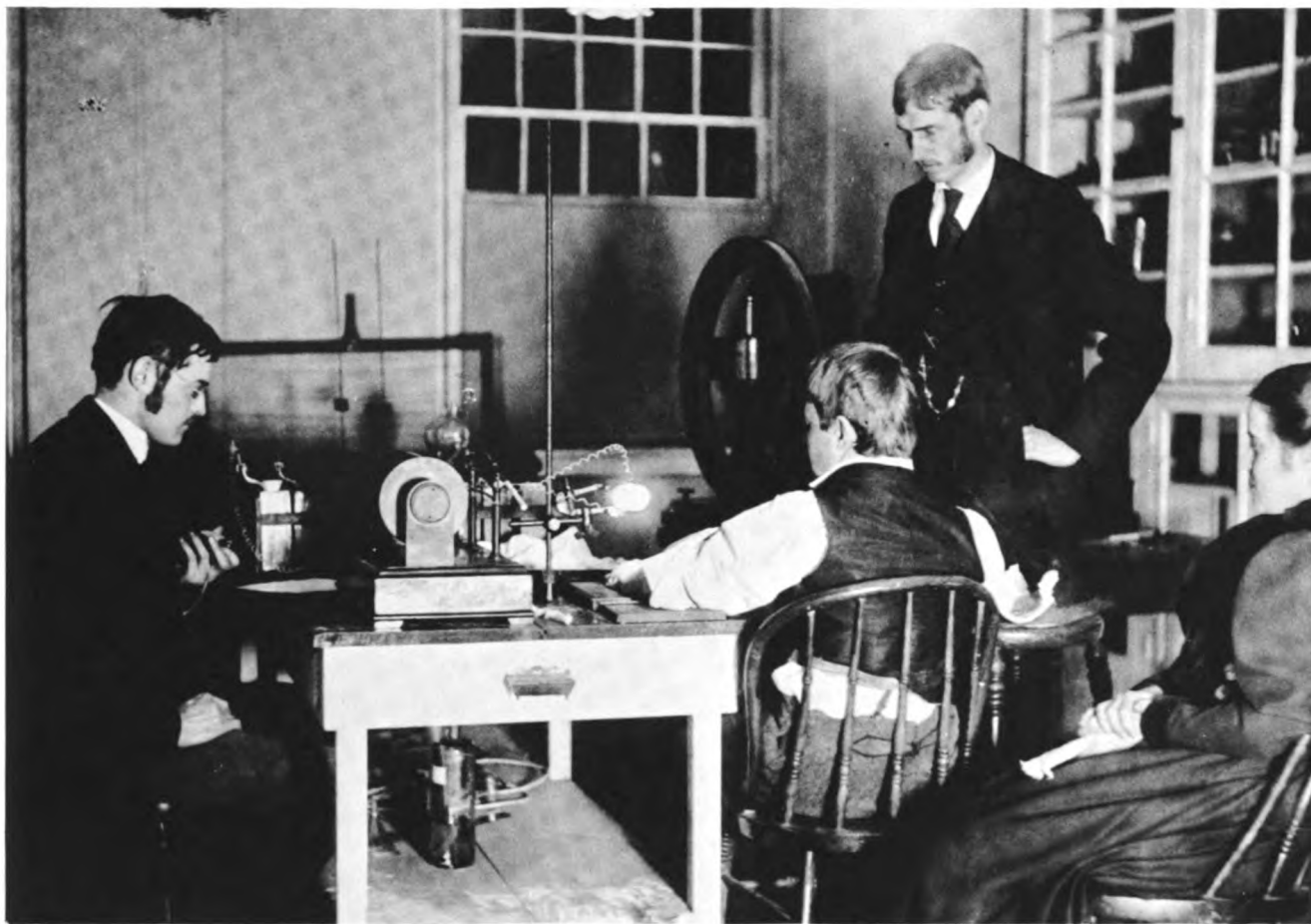
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To

ELMER BELT, M.D., LL.D.

*The fulfillment of whose Hippocratic Oath has
extended from Salerno and Vinci to Boston and
Los Angeles*

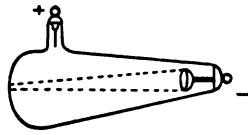


Courtesy, Dartmouth College Library

A FIRST APPLICATION OF X-RAYS IN AMERICA

Because no new apparatus was required to generate the new kind of penetrating rays discovered by Prof. Röntgen at the end of 1895, the news was flashed around the world and X-ray experiments were quickly repeated. One of the first applications to a medical problem was on 3 February 1896 when Prof. Edwin B. Frost of Dartmouth College, left, timed the exposure of the fractured arm of a young patient, while Dr. Gilman Frost, standing, directed, and Mrs. Frost watched.

THE NEW RAYS OF PROFESSOR RÖNTGEN



OF the five senses that man possesses, the one most precious to him is the sense of sight. The light-sensitive patch of skin that, thru the millions of years, evolved into a focusing pair of eyes, assured man, as it did his fellow creatures, an awareness of the world around him. Sight provided him maximum safety from enemies and alerted him to the presence of food or friend. When night came and the sun disappeared, primitive man, unable to see, became a fearful and helpless creature.

Unlike most other beings, man tried to extend his limited powers. Tho weaker in frame and with poorer hearing and smelling sensitivity than many of the other species that moved across the earth's face, he managed to develop hands, and thereby the ability to grasp, hold and use implements and weapons. With his new abilities, tools were wrought, shelters built and ways of making and keeping fire were developed. The night lost its fearsomeness and the day's usefulness was extended. Once blinded by the darkness, man learnt ways of extending his vision by the penetrating rays from his crude lamp.

With the introduction of the methods of experimental science about four hundred years ago, two major inventions extended man's vision at each end of his normal spectrum of visibility. During the first decade of the 1600s, from the Low Countries came news of the telescope. From there also, in the mid-1600s, came a stream of letters describing discoveries resulting from the newly invented microscope. And so man's vision went deep into the heavens, and fine into the structure of living tissue, from the macrocosm to the very fabric of the physical world.

During the succeeding centuries, improvements and refinements were made in the con-

struction and use of these instruments which opened new worlds to the observer at the eyepiece. This extended man's command and awareness of a scene in which he had become the principal actor.

Parallel with these advances in the field of optics a new discipline was born which followed the pattern of evolution. William Gilbert of England methodically gathered masses of empirical data and conflicting notions regarding magnetism and electrical attraction, and subjected them to the test of experiment. This dedicated investigator thereby founded the electrical science. Thru the subsequent centuries, new electrical discoveries were made and these were relayed thru exchange of scientific knowledge. The last years of the 1800s found the new science of electricity rich in its many discoveries, its growing number of laboratories and the new electrical appliances that brought new forms of light, heat and power thru the ever denser network of electric wires crossing every civilized land. Finally, at the close of the last century the news of a prime discovery flashed and reverberated across the world. Man had discovered a way of seeing thru opaque objects.

This momentous event occurred on a Friday evening in the laboratory of physics at the University of Würzburg in that ancient city on the Rhine. The Director of the Physical Institute of the university was experimenting with electrical discharges in high vacuum tubes. It was an extension of research into the strange properties that were observed when an electrical potential was applied to electrodes sealed into glass tubes from which the air had been exhausted. On this threshold evening of 8 November 1895 Professor Wilhelm Conrad Röntgen was repeating, as many others had done before him, a well known

experiment of applying a high voltage current from a Ruhmkorff induction coil with a mercury interrupter in the circuit to a Hittorf-Crookes vacuum tube. However, alone in the darkened room, Röntgen observed that some fine crystals which had been painted on a screen lying upon a nearby table at a distance from the apparatus had become fluorescent. The two laboratory assistants who usually were present during working hours had already left, so that the lone Röntgen could share the puzzle before him with no one.

Vacuum tube glow

The phenomenon of electrical excitation in a vacuum had long before been observed and described by Francis Hauksbee, curator of experiments and instrument maker to the Royal Society of London, which had elected him a Fellow in 1705. In a book published in 1709, Hauksbee described an unusual light glow that was visible when a glass vessel had been evacuated by an air pump, and a few drops of mercury were subsequently injected. When he shook the glass vessel, a phosphorescent glow was seen. A similar phenomenon had previously been observed in 1675, by Jean Picard who, in the darkness of his Paris observatory, had noted this glow in an exhausted barometric tube.

Hauksbee, continuing his extended series of experiments with exhausted glass vessels and mercury in friction, devised an important assembly of elements. Essentially, he mounted a glass globe about nine inches in diameter on lathe-like bearings and provided a wheel and crank to turn the globe. After the air was exhausted from the globe, it was revolved. On placing a dry hand on its revolving surface, he noted a purple glow within the globe of sufficient brilliance to permit reading of large type; the wall of the room, ten feet distant from the globe, also became visible. Hauksbee observed that as small amounts of air were permitted to enter the

globe, the glow diminished. Encouraged by these experimental successes, he replaced the glass globe with one of cylindrical shape on which he performed an extensive series of experiments that revealed unusual properties of attraction and glow. This ingenious experimenter then constructed dual rotating equipment whereby one glass cylinder was spaced within another so that each could be exhausted of air separately, and each could be rotated independently in the same or in opposite directions. With this apparatus he observed and described the first relationships of static electrical phenomena in exhausted vessels.

As early as 1819 Michael Faraday, then only 24 years old and writing on the various states of matter (such as the three then well known—solid, liquid and gaseous), added a fourth state—radiant matter. Altho not yet observed by any experimenter, it seemed to him a logical extension that “in physical properties accompanying changes of form, and which is perhaps sufficient to induce, in the inventive and sanguine philosopher, a considerable degree of belief in the radiant form with the others in the set of changes I have mentioned.” In the changes from the hard, opaque or colored, weighted and firm solid state, into the lighter, more transparent fluid and elastic forms of the liquid or gaseous state, Faraday noted a loss of certain properties. He then continued, “To those, therefore, who admit the radiant form of matter, no difficulty exists in the simplicity of the properties it possesses, but rather an argument in their favour . . . They point out the greater exertions which Nature makes at each step of the change, and think that, consistently it ought to be greatest in the passage from the gaseous to the radiant form.”*

The behavior of an electric current flow thru a gas followed the pattern described by Faraday in his description of a current flow thru liq-

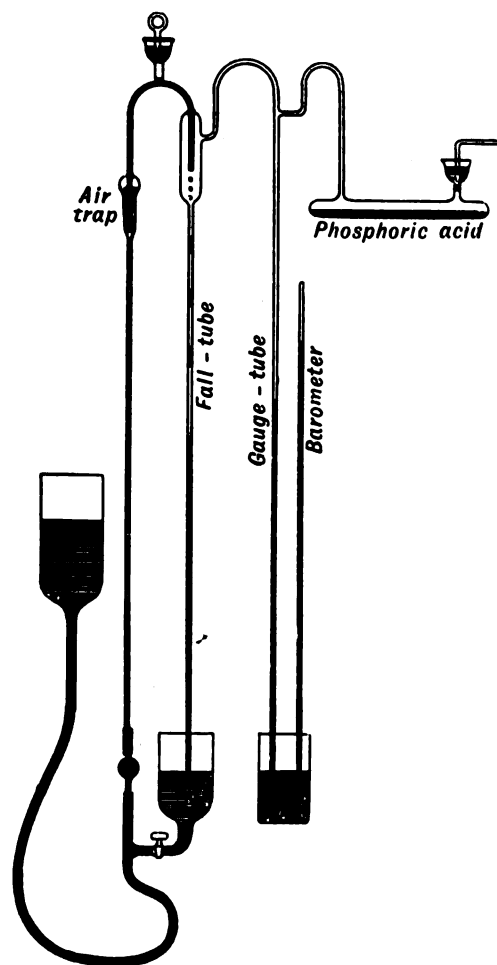
*COLWELL, H. A., *An Essay on the History of Electrotherapy*, London, 1922, page 134.

A bibliography of references is listed on page 55.

uids. He considered solutions and chemical compounds carrying currents to contain electrically charged atoms. Such liquids he called *electrolytes*. When a difference of electrical potential was applied to two points in an electrolyte, he concluded that the negatively charged particles moved toward the positive terminal and the positively charged ones moved to the negative terminal. Faraday designated these charged particles as *ions* ("travelers" in Greek)—carriers of electricity. Many years earlier he had also coined the words *anode* and *cathode*.

From the time Hauksbee first observed the electrical glow until that Friday evening when Röntgen made his phenomenal discovery, two important apparatus developments had been introduced. The first was a family of glass tubes of many shapes and sizes produced by Heinrich Geissler of Bonn in the 1850s. Geissler had been trained as a skilled glassblower and was called upon to form complex physical and chemical glass shapes. He thus became involved in the problems of physics and chemistry and gradually participated in the experiments themselves. In 1852 with Julius Plücker he determined that the maximum density of water was reached at 3.8°C. Geissler assisted the electrical experimenters and then, on his own, succeeded in changing ordinary phosphorus into an amorphous kind by the application of an electric current.

Geissler's skill in the construction of scientific apparatus also produced the second major improvement—an advanced form of mercury air-pump. With this new pump, air was efficiently extracted from glass tubes which were then sealed upon electrodes inserted at their ends. To these he applied high voltage currents. By admitting small quantities of various gases into these tubes, brilliant and subtle glowing colors were obtained; these helped physicists and chemists to determine characteristics of the gases as well as the applied currents. The University of Bonn, in appreciation of his contributions to the experi-



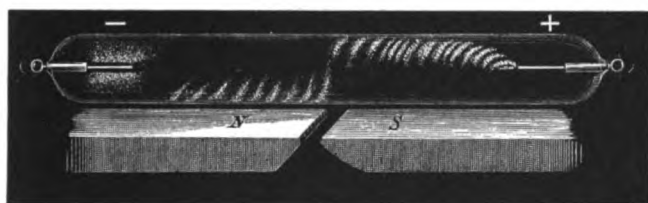
S. P. Thompson, *Light Visible and Invisible*, 1897.

Air Evacuation Pump

For the higher vacua required in cathode ray and X-ray experiments, a mercury rather than a piston type of air-pump was developed. Dr. H. Sprengel invented this pump in 1865; Crookes added important improvements.

mental apparatus which he supplied to her laboratories, conferred an honorary degree of Doctor of Philosophy upon him during its jubilee year of 1868.

The burgomaster of Magdeburg, Otto von Guericke, the builder of the earliest electrical machine, was also the inventor of the earliest air pump, which he introduced in 1654. This was a



Urbanitzky, Electricity, London, 1890

Magnetic effects on a Geissler tube

By exhausting the air from a glass tube to less than 1/1000th volume and applying a high voltage current to the terminals, a luminous effect, often striated, resulted. Applying a magnet to this beam caused attraction or repulsion, as shown above.

piston-type pump which was adequate for the early experiments performed so successfully by Robert Boyle and Robert Hooke. The demonstration by Torricelli of the inverted-column barometer first demonstrated a method of obtaining a complete vacuum, known as a Torricellian vacuum.

Geissler's improved air-pump consisted of two glass vessels connected by a long narrow rubber tube able to withstand 20 p.s.i. The upper vessel was connected by a stopcock to the container to be exhausted. Mercury was then added to both vessels and to their connecting tube. By then raising and lowering the free vessel and the volume of mercury and timing the action with the opening and closing of the stopcock above the fixed vessel, each such motion exhausted another portion of the remaining air in the apparatus. The greater the number of times the free vessel was lifted and lowered, the fewer particles remained in the apparatus. By careful coordination, the pressure in the exhausted apparatus was lowered to one twentieth millimeter of mercury, but absolute vacuum could not be attained because of the film of air that clung to the walls of the equipment and to the mercury. Later, an improved air pump was devised in which drops of mercury descended a narrow glass tube to which the apparatus to be exhausted was connected at a favorable angle, so that each falling mercury

drop entrapped a volume of air which the mercury carried down into a pneumatic trough. This produced a very high order of vacuum.*

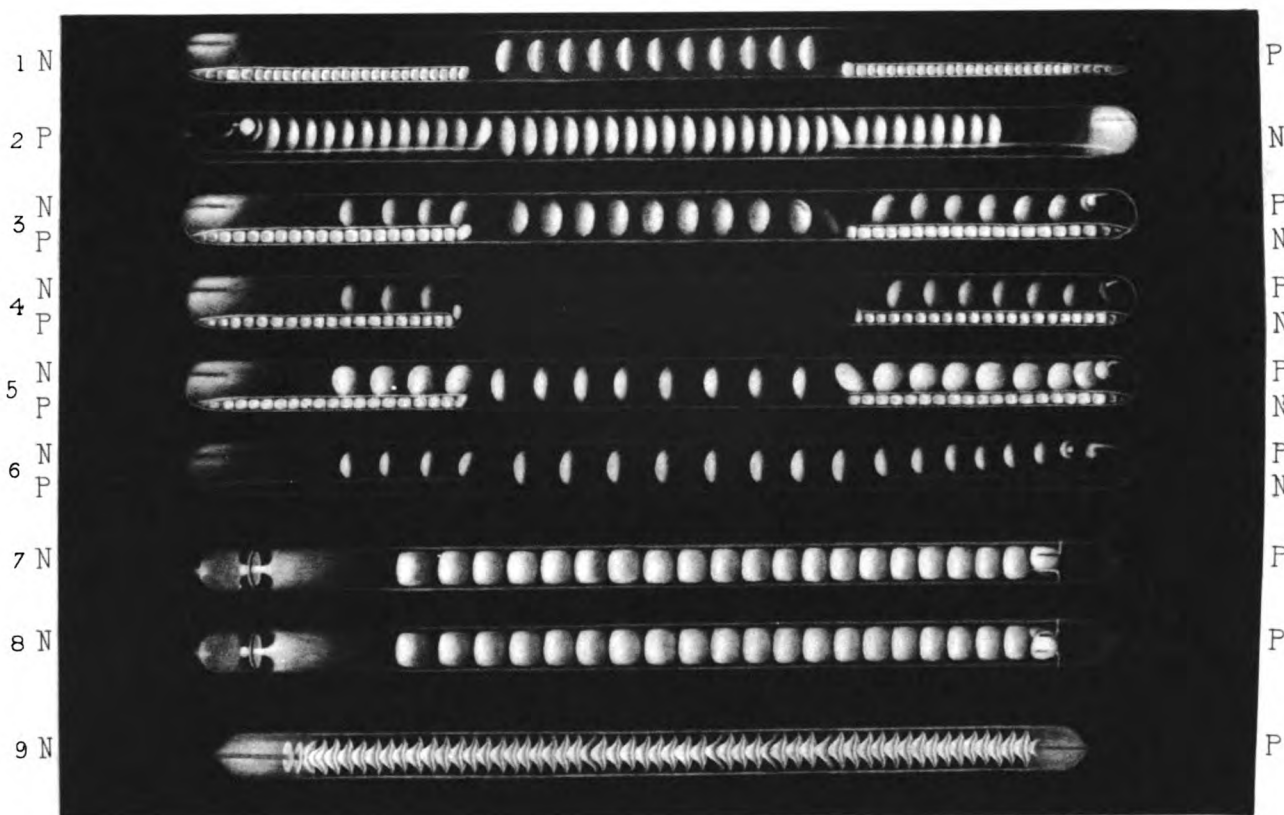
Using his air-pump, Geissler in 1857 formed a number of glass tubes into the ends of which he fused platinum wire terminals and exhausted these tubes to about one hundredth atmosphere. By applying electrical discharges from a Ruhmkorff coil, Geissler produced luminous effects of extraordinary beauty.

The discharges in Geissler tubes were also investigated by Julius Plücker, professor of physics at the University of Bonn, who first observed that the column of luminescence was striated. He then discovered that the diffused light at the cathode could be concentrated with the use of a magnet, a condition he observed for any kind of gas in Geissler tubes. Plücker published a paper at Bonn in 1857 in which he asserted that particles of the platinum cathode were deposited on the glass of the tube, that the glass wall near the cathode became hot and phosphorescent during the discharge, and that the cathode rays (which he observed but did not identify) could be deflected by a magnet which was also capable of moving the phosphorescent spot.

Johann W. Hittorf, formerly one of Plücker's pupils and later professor of physics at the Academy in Münster, improved the degree of vacuum in the tubes and observed that, when a screen was placed in the path of the ray, a shadow on the phosphorescent spot resulted; he therefore concluded that the discharge moved in straight lines. Eugen Goldstein of the Berlin Observatory first used the term "cathodic light, cathodic rays"*** in a report at Berlin in 1876.

*A dozen years ago high vacuum reached a range of 10^{-8} torr (equal to a pressure of a hundred millionth of a mercury column one mm. high). The "torr" was named after Evangelista Torricelli (1608-1647). Now a pressure of 10^{-12} is attainable, with 10^{-15} , and the low pressures of interplanetary space, a present target for laboratory techniques.

**SARTON, George, "The Discovery of X-rays" in *ISIS*, March 1937, p. 352.



De La Rue and Müller, Electric Discharge, Phil. Trans., 1883

Geissler Tube Fluorescence

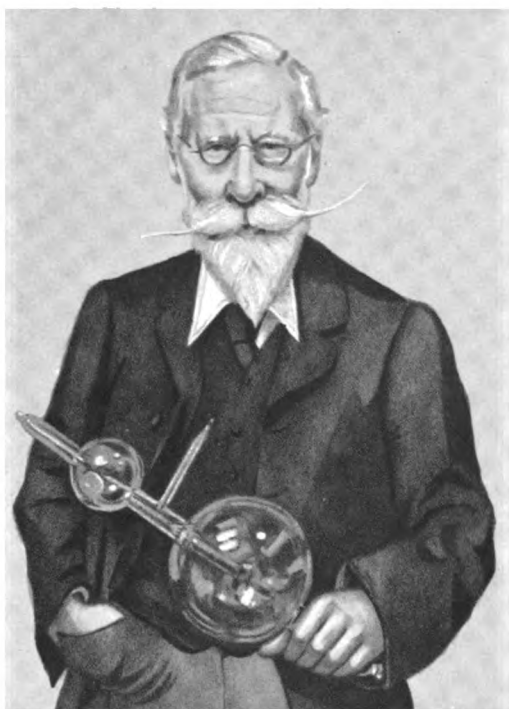
A pulsating high-voltage current applied to vacuum tubes in the 1880s created beautiful patterns of glow, depending on the nature of the occluded gas, the applied voltage and the degree of exhaustion.

Cathode rays

William Crookes (1832-1919) devised apparatus for obtaining very high vacuum. Experimenting with rarefied gases, he concluded that the true nature of cathode rays was negatively charged particles, producing considerable heat if stopped. He also demonstrated by the radiometer, which he had invented in 1875, that the impact of these particles could be converted into mechanical rotation. Both Hittorf and Crookes had built tubes in which cathode rays were concentrated by a cathode of concave form upon a

platinum foil. As early as 1879 Crookes demonstrated that the cathode stream striking the platinum plate caused it to glow white hot. What was not realized at the time was that thru this means X-rays were also being generated.

Crookes saw in the glow of the Geissler tubes a phenomenon worthy of intense investigation. In the late 1870s he devised a glass tube with fused terminals in which he was able to rarefy the contained gas to an order of a millionth atmosphere. Experimenting with this tube, Crookes was able to demonstrate the properties of luminous rays emanating from the cathode. A controversy arose as to the true nature of the

*Vanity Fair Series*

Sir William Crookes

The major contributor to high vacuum technology was the inventor of the improved air-pump, the Crookes high-vacuum tube and the radiometer (light-mill). He formulated laws of cathode ray emanation and postulated a fourth, or "radiant", state of matter but missed observing X-ray phenomena.

cathode rays. Crookes and his supporters, mostly English, maintained that they were emanations of particles. Most German experimenters held the view that they were disturbances in the ether and that their character was similar to ultraviolet rays. J. J. Thomson of Cambridge confirmed, in 1897, that cathode rays consisted of negatively charged particles (electrons), thereby confirming Crookes' position.

The research work done by Crookes on the cathode ray established a number of its properties. These discoveries were among the most important of the second half of the 1800s and led directly to Röntgen's great discovery and our en-

try into the atomic age. Crookes concluded that the faint light which emanated perpendicularly from the cathode surface moved in straight lines irrespective of the position of the anode. In vacuum tubes having a relatively low vacuum, the glowing bands would turn corners and enter side tubes so as to reach the anode. The fluorescence which was produced resulted from impact on solid material in the ray's path. This impediment might be the walls of the tube itself or some other solid placed between cathode and anode. Crookes fashioned a maltese cross of metal, set it in the ray's path and observed the equivalent shadow projected upon the wall of the tube. Minerals and gems such as diamonds or rubies placed in the path of the rays glowed with distinct and vivid colors. As in his other famous invention, the radiometer, Crookes placed a pivoted light metal wheel of vanes in the path of the rays and watched them turn from the impact of electrified particles on the vanes. That the rays generated heat was demonstrated by concentrating them by a concave cathode upon pieces of metal. Even platinum was fused by the intense heat. Finally, Crookes confirmed that the stream of cathode rays could be deflected by bringing a magnet close to the stream. The results of the systematic examination of this phenomenon by Crookes were presented in the Bakerian lecture for 1878 in which he analyzed the changes in the appearance of the discharge with the gases varying in pressure from 68 mm. to 0.078 mm. of mercury. As the degree of vacuum increased, Crookes observed that a dark area was formed around the cathode and that it expanded with higher vacua. Regarding the cathode rays as streams of molecules moving in specific directions, as shown by the expansion of a dark space, he concluded that higher vacuum offered less resistance to the stream of rays.

Among those who held a different view of the nature of cathode rays was Heinrich Hertz (1857-1894) whose investigation of electromagnetic radiation in the ether had been indica-

ted by Maxwell's calculations. Hertz discovered that cathodic rays were able to penetrate thin metal sheets but that they emerged from them in a disturbed state, like light passing thru a turbid liquid. In 1892 Hertz had written, "Cathode rays are significantly different from light rays in that they have the ability to penetrate solid bodies."* Two years later, in 1894, Philipp Lenard, a pupil of Hertz, added a thin metal window to a Geissler tube and confirmed Hertz' diffused rays issuing from the metal and showed that phosphorescent action by them extended only about 2 to 5 cm. beyond the tube. Hertz, having observed the passage of cathode rays thru sheets of silver, aluminum, tin, zinc and copper, and having observed the dark shadows cast by mica, suggested to his pupil Lenard that aluminum least hindered the passage of cathode rays and that these probably extended beyond the tube. As one contemporary investigator reported, "The experiments of Hertz were carried on within the vacuum tube, but later, Lenard, at the instance of Hertz, carried out some important further experiments in which the cathode rays were obtained *outside* the tube, and their properties carefully examined."**

The Crookes tube

Whereas, in ordinary air, it required a potential difference of nearly a million volts to penetrate an air gap a foot in length, the voltage needed to penetrate an equivalent length of partially exhausted space in a long vacuum tube was considerably reduced. Watching the continued process of exhaustion from such a tube, one observed the beginnings of a pale white light established between the electrodes within

the tube ends. On further exhaustion, a purple quivering beam of light became visible which, with higher vacuum, broadened into a misty crimson glow which ultimately filled the entire tube. Further evacuation, to the order of a millimeter of mercury or less, strengthened the light closer at the anode and somewhat away from the cathode, leaving a recognizably dark space first observed by Faraday, and therefore known as the *Faraday dark space*. A bright violet-bluish glow clung to the cathode which also developed a narrow dark space first seen by Crookes and therefore called the *Crookes dark space*. Still further exhaustion caused the positive beam to break up into a number of striations and quivering discs of light. Beyond this state of vacuum, further withdrawal of gas increased the electrical resistance and the diminution of the glow and the gas particles to support it. Finally all visible manifestations stopped.

As Crookes saw it, the beam of cathode rays constituted a torrent of molecules of the residual gas in the tube. These were attracted to the cathode, acquired a negative electrical charge from it and, because of the similarity of the electrical charges, were then repelled in a direction perpendicular to the cathode surface. The Crookes dark space, developed and expanded by the rebound of more highly charged molecules from the cathode into the slower moving advancing particles, indicated the boundary of conflict. Where the charged particles struck the inner glass walls of the tube, a phosphorescent or fluorescent glow resulted. Crookes also observed that two parallel beams of cathode rays seemed to repel one another, thereby tending to confirm the electrically charged character of the particles. However, the reason for this mutual repulsion was later ascribed to another cause.

Crookes pointed out* that Dr. Wright of Yale College had reported as early as 1877 that

*SARTON, "The Discovery of X-rays", in *ISIS* for March 1937, p. 353.

**BOTTOMLEY, Dr. J. T., "The Discoveries of Hertz, Lenard and Röntgen", in *Proceedings, Philosophical Society of Glasgow*, 5 Feb. 1896, p. 158.

*CROOKES, William, "On Electrical Evaporation", in the *Proceedings of the Royal Society*, Vol. 50, 4 June 1891.

a fine film of blackened metallic platinum was deposited on the inner surface of a vacuum tube. He stated that the intense heat caused by the electrical discharge, as well as the absence of any air pressure in an evacuated tube, prompted the release of molecules of the electrode metal and its deposition on the inner tube surface.

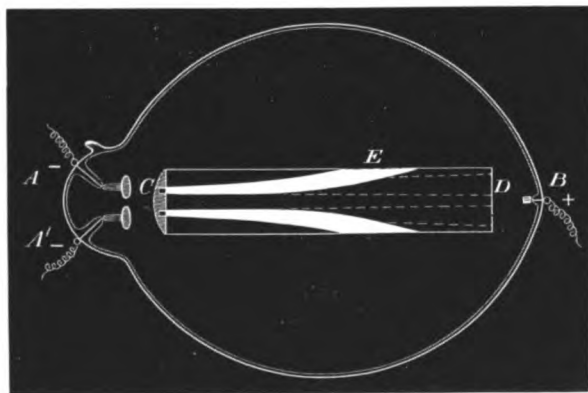
In his famous inaugural address as president of the Institution of Electrical Engineers, Crookes outlined some of the then recent advances in vacuum tube technology. In the review of over a score of experiments, he showed how a stream of ultra-gaseous particles of radiant matter "does not carry a current of electricity, but consists of a succession of negatively electrified molecules whose electrostatic repulsion overbalances their electro-magnetic attraction, probably because their speed along the tube is less than the velocity of light."* He fastened the positive electrode of an induction apparatus to B. He then fastened the negative terminal to one electrode at A and A'; either one of the two parallel streams of radiant matter was made

visible by impinging on a screen of phosphorescent substance thru holes in a mica diaphragm.

With the tube exhausted to 0.1 mm. and the negative terminal attached to only one of the two electrodes A, the beam traveled parallel to the axis of the tube, CD. On connecting the negative terminal to both A electrodes, two parallel streams of radiant matter were energized and were seen to diverge, indicating that these were two streams of electrified molecules rather than streams similar to wires carrying a current. Crookes speculated that if the velocity of the streams of molecules was greater than that of light they attracted each other and behaved like electrical conductors.

At this session, Crookes also repeated two of his most famous experiments. In the first he connected the positive electrode to a silver patch B at the top of the tube and the negative electrode to a smaller patch A. At the center he inserted a cross cut from mica. With an internal pressure of 0.00068 mm., he energized the tube and showed, on the opposite side, the clear black shadow of the cross in the otherwise phosphorescent glow. An equally dramatic demonstration of the mechanical energy represented by the radiant matter stream was shown in the spherical tube containing a delicate wheel with vanes of transparent mica. The electrodes were fastened to the outside of the tube. When the current was applied, the wheel revolved; when the current was reversed, the wheel rotated in the reverse direction.

Crookes emphasized that none of the metallic electrodes in the series of experiments penetrated the glass tube; all were fastened to the outside. It was then asked whether the glass itself was not energized and particles torn from the glass sides and projected across the tube space. Crookes had painted a coat of yttria on the inside of the tube over the area covered by the silver negative electrode fastened to the outside of the tube. When energized, there formed within the tube the characteristic dull blue of the lead glass,

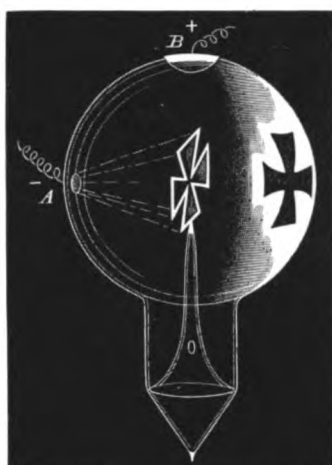


Crookes, Electricity in Transitu, 1891

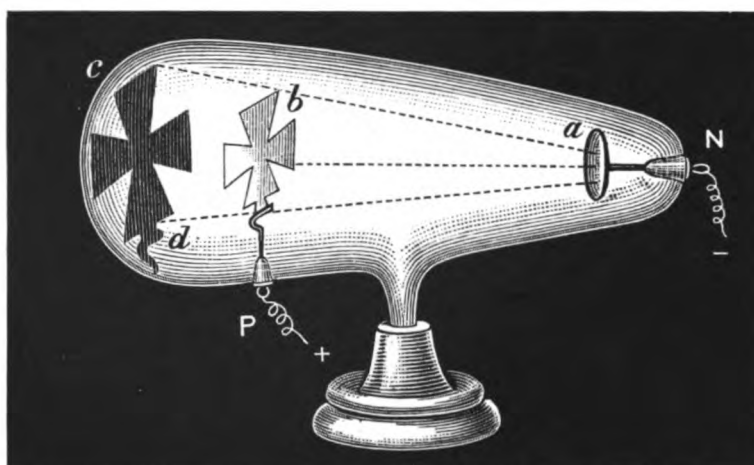
Repulsion by cathode rays

A demonstration by Crookes proved that two beams of negatively electrified radiant matter diverged because the electrostatic repulsion overbalanced the electromagnetic attraction, and indicated that the velocity of the particles was less than that of light.

*Address delivered 15 January 1891, pages 16, 30 and 32.



Crookes, Electricity in Transitu, 1891



Crookes, Radiant Matter, 1879

Cathode ray shadows

Crookes placed a maltese cross of mica inside a vacuum tube facing a silver cathode. When energized by an induction coil, the bulb or tube glowed with a phosphorescent light that cast a dark shadow of the cross on the tube wall.

but not the golden yellow of yttria. This proved that the glow was the radiant matter of the residual gaseous molecules and was not torn-off particles of the negative electrode.

In an additional experiment, Crookes arranged a maltese cross of aluminum in the center of a pear-shaped tube and observed the glow upon the glass, except the shadow of the cross which remained dark. However, he observed a diminution of the strength of the phosphorescent glow with successive uses and, to verify this, he arranged a tube in which, by tipping the tube, the cross (the anode) would fall down. On next energizing the tube, he observed that the cross area glowed more brilliantly than the rest of the tube. E. P. Thompson believed that the cathodic metal first deposited on the tube walls explained the sequence of reduced glow.* The observation of radiant matter in 1879 by Crookes led him to remark prophetically, "Here lie ultimate realities."

The observations and theories of Crookes

prompted other physicists to repeat and expand the experiments, particularly in England and Germany. Heinrich Hertz observed that the cathode rays generated no external electric or magnetic forces, nor were they affected by an electrostatic field, tho Goldstein did accomplish the latter in 1876. Many investigators studied the problems of cathode ray phenomena, trying to establish exact laws of behavior. At the end of 1891 several German investigators, including Hittorf and Wiedemann, observed the penetrating power of the rays; Hertz and his assistant Lenard made a more thoro investigation. The latter, in 1894, managed to insert a thin sheet of aluminum as a window in the end of a tube, thru which the discharge penetrated. It seemed so difficult to conceive the passage of any rays thru an opaque metallic sheet that logical explanations to clarify the phenomenon were sought. J. J. Thomson suggested that the particles constituting the ray on either side of the metallic membrane were not integral, but that the rays on the outer side of the film were emitted from the film itself.

*THOMPSON, Edward P., *Röntgen Rays*, New York 1896, page 41.

The student from Apeldoorn

The next link in the elaborate chain of progress and discovery of electrical discharges thru rarefied gases occurred in the physics laboratory of the University of Würzburg. Here Professor Wilhelm Conrad Röntgen had set up the usual combination of an induction coil and a Crookes tube, but a fluorescent screen happened to be lying nearby on the laboratory table. The events that followed opened a new chapter in the history of science.

Röntgen was born in the Rhineland town of Lennep on 27 March 1845. His father was a local cloth merchant and his mother a native of Holland, born in Amsterdam; they were first cousins. Altho his ancestral families were large ones, Röntgen was an only child. His parents, when he was three years old, sold their home in Lennep and moved to join his mother's grandparents (named Frowein) at Apeldoorn in Holland. By this move the father changed his Prussian citizenship to that of Holland.

In Apeldoorn young Wilhelm followed the usual preliminary schooling by enrollment at the van Doorn Institute where he supplemented his formal studies by wandering with companions thru the forests and fields. He early displayed mechanical aptitude by building various devices, one such being the construction of a small suction pump to hasten the seasoning of a meerscham pipe which his uncle had presented to him.

During the last days of 1862, Röntgen began his studies at the Utrecht Technical School in preparation for the Technical High School, a goal that required two years of study. In January 1865 Röntgen entered the University of Utrecht but, in less than a year, he followed the suggestion of a Swiss friend and took the entrance examination for the Swiss Polytechnic Institute at Zürich. In November of 1865 he became a student in mechanical engineering at that famous technical university.

Röntgen faced his new studies and location with high spirits and great happiness because of the beauty of Zürich; its attractive lake and mountain peaks matched the avid cultural atmosphere of the community. Realizing his good fortune, Röntgen accepted the opportunity for serious study that lay before him and buckled down seriously to the rigors of an engineering discipline. Altho the courses were hard, thruout the rest of his long life he thought back on his Swiss student days as the happiest. The completion of his studies in Switzerland ended a period of education outside his native Germany that lasted from his third to his twenty-fifth year.

At Zürich, Röntgen studied under the eminent Rudolf Clausius, formulator of the second law of thermodynamics. Röntgen was especially impressed by the presentation and experimental demonstrations by Clausius on the mechanical theory of heat which, to Röntgen as a student of mechanical engineering, was of great importance.

Of all the professors who helped shape his mind during the formative years, the one who proved of greatest influence was August Kundt, a brilliant experimental physicist. Kundt, only 29 years old at the time, arrived at Zürich several years after Röntgen, to replace Clausius. With modest equipment, Kundt organized his courses in physics for both the regular students and those with special aptitudes.

Röntgen graduated as a mechanical engineer in 1868 but continued his studies at the University of Zürich so that in June of the following year he obtained his degree of Doctor of Philosophy after submitting a thesis titled "Studies on Gases". On the invitation by Prof. Kundt he became his assistant and the two worked together until both professor and assistant transferred to the University of Würzburg in the department of physics.

Since he was an only child, Röntgen's parents were very anxious to see him married to the daughter of some prominent and wealthy family. Altho they gave their consent, there was there-

fore some disappointment when, in January 1872, Röntgen returned to Apeldoorn to be married to Anna Bertha Ludwig. The bride, daughter of a former student at the University of Jena who had fled that Thuringian city in the 1830s during a revolutionary uprising, was six years his senior and was in poor health. Her birthplace was Zürich where her father conducted a cafe which was popular among students and professors, for the proprietor was himself a man of unusual intelligence, steeped in poetry and the classics. Thus Apeldoorn once again became a vital center in Röntgen's life and fitted well with the nickname "Apeldoorn" which his fellow students at Zürich dubbed him. The young couple occupied a very small and modest house and the bride did all her own cooking, washing, sewing and mending.

Röntgen, a tall and handsome man, alternated his duties of intensive studying and teaching with visits to the mountains of his beloved Switzerland. He was an ardent mountain climber and on several occasions found himself in dangerous situations, one such resulting in a fall that required serious medical attention. His simple tastes often caused him to prefer passage over mountain roads on horseback rather than the quicker, more comfortable railroad.

The first bloom of promise at the University of Würzburg quickly faded when two shadows of his past academic record became known to his colleagues. His expulsion from the Utrecht Technical School because of his unwillingness to name the true culprit in a typical student prank, remained part of his record. More serious in those days was Röntgen's failure to master the classic languages (a hallmark of the old German university tradition), particularly important for an aspiring professor. Röntgen therefore did not receive a full academic appointment, Kundt's high praise of his abilities notwithstanding. This disappointment was short-lived for, in 1872, both Kundt and Röntgen accepted appointments to the faculty of the newly established University

of Strasbourg. This city was then the capital of the imperial province of Alsace-Lorraine, newly won territory by the Germans in the Franco-Prussian war. The university, originally founded in 1567, had been closed during the French Revolution but was reestablished during the German occupation with a new administration and faculty.

Under these fresh circumstances the progress of Röntgen, altho only a "Privat Dozent", or Instructor, in status, was nonetheless unhindered and satisfying. While Röntgen was at Strasbourg, his favorite uncle Ferdinand emigrated to America and his parents left Apeldoorn to join their son, thus reuniting the small family. Three years later, in April 1875, Röntgen again changed academic posts to become professor of physics and mathematics at Hohenheim in Württemberg, but this stay was short because he found the physical facilities there quite inadequate and limiting. After a little more than a year, Röntgen rejoined Kundt at Strasbourg as professor of theoretical physics.

During the seven years that he spent at Strasbourg, Röntgen investigated a wide variety of problems in physics ranging from the determination of specific heats, electrical discharges, the sun's radiation, telephonic improvements, electromagnetic rotation and the properties of crystals. It can thus be seen that he recognized there was important research to be done in electrical discharges in gases and insulators. He also realized that the crystalline structure of matter embodied some of the most complex and important laws of nature. His interest in the physical and electrical properties of crystals continued for the rest of his life.

His work now began to appear in publications and attract interest in the rapidly expanding field of physics. This led to an invitation, in 1879, to become professor of physics at the University of Giessen in Hesse, an important post which he accepted when only 34 years old. Here he remained for eight years, expanding the



Using a voltaic battery as an energy source and an electromagnetic or mercury interrupter, two coils, wound over an iron wire core, produced high-voltage pulsed currents that created X-rays in a vacuum tube. Adding Tesla coils and condensers across the gap terminals produced more penetrating rays.

While at Giessen, Röntgen intensified his research of electro-magnetic and gas phenomena on pyro- and piezo-electrical properties of crystals and on surface phenomena of liquids. Also at Giessen, Röntgen undertook an extensive investigation of the "Rowland effect". H. A. Rowland, an American, had shown that a charged body in motion produced a magnetic field similar to that generated by an electric current in a conductor. In 1888, Röntgen formulated his proof that when a dielectric is moved between two electrically charged condenser plates, magnetic effects result. He later considered this contribution as having importance equal to that of his discovery of X-rays.

garded, that it was presented to the Royal Prussian Academy of Sciences in Berlin in 1888 by von Helmholtz. It has been considered as a major contribution leading to the transformation of Lorentz and the relativity of Einstein. This was his final important work at Giessen University which he left for Würzburg with the reputation of a scientist of the first rank. Before leaving, Röntgen wrote to Hertz informing him that he was recommending him as his successor at Giessen and urged Hertz to accept the professorship.

Some of the happiest years of Röntgen's fruitful life were spent in Giessen where he worked, published and lectured to an increasingly large circle of students and colleagues. Hard work often gave way to hard play with exploratory trips into the mountain areas and up the beautiful Rhine. Both of his parents died during his stay in Giessen.

While undramatic, Röntgen's reputation as a sound physical experimenter and analyst prompted two universities, Jena and Utrecht, to seek him for their faculties. The latter invitation pleased him particularly because it served to efface the blot on his academic career which had occurred at Utrecht. Still another call, again from the University of Würzburg, in October 1888, was heeded by Röntgen. Its renowned Professor Kohlrausch had moved on to Strasbourg and it would have enhanced anyone's reputation to be his successor. Röntgen therefore became Professor of Physics and Director of the new Physical Institute, his fourth professorial post. The 16 years that had passed between the first cool reception given by Würzburg to Röntgen and the present invitation reflected his recognized excellence as a teacher and the respect for his reputation as an experimenter.

This ancient university (founded in 1402) had long fostered the physical sciences. Here



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Prof. Wilhelm Conrad Röntgen

A portrait taken in early 1896 at the time of his important discovery. His impressive head and tall frame were matched by a deep dedication to science and a modest attitude toward his accomplishments.

the Jesuit physicist Casper Schott (1608-1666) had taught, and one of the earliest chairs in experimental physics was established in 1749. This great step led to the separation of science from philosophy (and physics from metaphysics). The bold move was supplemented in 1773 when a professorship in theoretical physics was established. Röntgen joined a famous roster—Weber, Helmholtz, Clausius and Kirchhoff—and helped add Würzburg to the most important German centers of scientific development of the 1800s. It now boasted 1500 students, 53 professors and 40 assistants.

When Röntgen moved on to Würzburg, he

began his third most important series of studies and publications, the first two having been at Strasbourg and Giessen. Here his published works were concerned with the electro-dynamic effect of moving dielectrics, the compressibility of water and a number of other liquids and the variation of refractive index of liquids under pressure. In electrical research he published results on the influence of pressure on the conductivity of electrolytes and other liquids. The crowning publications, his 49th and 50th, were "On a New Kind of Rays".

When Röntgen became Rector of the University of Würzburg in 1894, he repeated in his inaugural address the words of a professor who had preceded him some two centuries before—Athanasius Kircher (1601-1680), professor of natural philosophy at Würzburg. Kircher, who had first observed thru his own microscope the circulation of blood in the tail of a small fish in 1646 and who had written a book on magnetism in 1641, had stated, "Nature often allows amazing miracles to be produced which originate from the most ordinary observations and which are, however, recognized only by those who are equipped with sagacity and acumen and who consult experience, the teacher of everything."* Little did Röntgen realize that before the passage of a year these very words would apply to him.

In a period rich in discovery, the contributions of Hittorf, Crookes and Hertz had opened a field that challenged the most competent experimental talent. Röntgen added to the potential of cathode rays on that fateful Friday evening of 8 November 1895 when, alone in his labora-

*GLASSER, Otto, *Wilhelm Conrad Röntgen and the Early History of the Roentgen Rays*, London, 1933, page 73. This comprehensive study of over 500 pages is an example of dedicated scholarship in the history of science. One important event and the personality that initiated it is treated with thoroughness and authority by one who devoted his full life to roentgenology. Based on a German edition of 1931 it was modernized in a new Springer edition in Berlin in 1959. Further reference to pages will mean the above English edition. Dr. Glasser continues as professor of Biophysics at Cleveland Clinic Foundation in Ohio.

tory that was darkened so as to observe the effectiveness of a black cardboard cover over a Crookes tube, he observed the phosphorescent glow of a screen of fine crystals on a nearby table. The Crookes tube had been covered when it was activated but Röntgen had noticed a peculiar black line across a sheet of paper treated with barium platinocyanide.* Since no light could issue from the covered tube, Röntgen was at a loss to understand the effect on the paper. Since the only possible source of radiation in that darkened room could be the tube, he immediately investigated this source.

A new kind of rays

In the knowledge of cathode rays of his day, it was not easy to bridge the space gap between the tubular glow and the observed fluorescence several feet away. The crystals were therefore replaced by a screen coated with barium platinocyanide placed at several distances beyond the then known penetrating ranges of cathode rays. Yet the screen continued to glow, indicating rays of extraordinary power (or possibly of an entirely new kind). Instead of lengthening the distance between screen and tube, Röntgen interposed obstructions of various kinds, including a book and articles of wood and metal. The rays penetrated the book altho with some reduced intensity. Wood offered little resistance and, of the sheet metals, only lead and platinum seemed to obstruct the rays completely. He observed that hard rubber, ebony and black cardboard were more transparent than glass or fluorspar.

(Röntgen then placed his own hand transverse to the rays and saw the macabre pattern of the bones of his hand set in a fainter outline of the flesh. To capture this spectral sight, Röntgen replaced the screen with a photographic plate to record a sight never before seen by man.

*S. P. Thompson of London had used a luminescent screen of barium platinocyanide since 1878. See his *Light, Visible and Invisible*, London, 1897, page 241.

It became clear to him that this was a new form of light, invisible to the eye and which had never been observed or recorded.

Having grasped the probable meaning of this new manifestation, Röntgen began to determine its properties. There followed eight weeks of the most careful repetition of the experiments, Röntgen checking each item of equipment, each procedure and every observation to be certain that no element had been overlooked. He shared his perplexities with no one, neither at home nor with his two assistants, but the strain on him became evident in his features and in his behavior. He at first ate and slept in the laboratory to avoid any distraction or interruption. Only once did he mention to one of his few very good friends, Theodor Boveri, "I have discovered something interesting but I do not know whether or not my observations are correct."

Röntgen constructed a sheet metal cabinet about seven feet high and four feet square at the base in order to have a permanent dark room instead of having to drape his laboratory with ineffective blinds and curtains. Into one side of the zinc-walled chamber he inserted a circular aluminum sheet 1 mm. thick and about 18 inches in diameter thru which the new rays would pass. A zinc door on the side of the booth opposite the aluminum disc permitted his entry and exit. The vacuum tube was placed outside and focused upon the disc's center.

Röntgen made no private announcement among his associates or friends until he had thoroly convinced himself that what he had seen was novel and important. Knowing that the announcement of such a discovery could not be long delayed, he prepared a short manuscript in the form of a preliminary report which he handed on 28 December 1895 to the president (or secretary) of the Physical Medical Society of Würzburg, a rather obscure organization for so momentous an announcement. In this report Röntgen stated simply that when a Crookes-type vacuum tube was energized by a large induc-

Courtesy. Röntgen Museum.
Lennep

EINE NEUE ART

VON

STRAHLEN.

DR. W. RÖNTGEN,
 11, GRIFFITHS AVENUE, E. GLENVIEW, ILL.

WÜRZBURG
 VERLAG UND DRUCK: VERBUND VERLAGS- UND DRUCK-UNIVERSITÄT
 DRUCK UND KUNSTHANDLUNG
 JULI 1998

00 21-

Lagerstätte kann? Sie erfahren, was
 anders ist, und was die Leistungen sind.

Aus der Sammelreihe der Harburger Plakatmoder. Gesellschaft 1926

W. C. Röntgen: Ueber eine neue Art von Strahlen.
(Vorläufige Mittheilung.)

1. Leert man durch eine *Hilfsbohrung* Vaconuübrü, oder einen genügend erweiterten *Leertkanal* in *Teuchelchen* oder ähnlichen Apparat die Entladung eines größeren *Rohrkohls* gehen und isoliert die Rohre mit einem ziemlich eng anliegenden Mantel aus einem schwarzen Carton, so sieht man in dem vollständig verdunkelten Zimmer einen in die Nähe des Apparats gebrauchten, mit Bariumplatinacyanid angereicherten Papierschirm bei jeder Entladung hell aufleuchten, fluorescieren, gleichgültig ob die angereicherte oder die andere Seite des Schirmes dem Entladungsschirm zugewandt ist. Die Fluoreszenz ist auch in 2 m Entfernung vom Apparat bemerkbar.

Man überzeugt sich leicht, dass die Ursache der Fluoreszenz vom Entladungsgarret und von keiner anderen Stelle der Leitung ausgeht.

2. Das an dieser Erscheinung zunächst Auffallende ist, dass durch die schwarze Carbonhülle, welche keine sichtbaren oder ultravioletten Strahlen des Sonnen- oder des elektrischen Bogens hindurchlässt, ein Agens hindurchgeht, das im Stande ist, lebhaftes Fluorescenz zu erzeugen, und man wird deshalb wohl zuerst untersuchen, ob auch andere Körper diese Eigenschaften besitzen.

Man findet bald, dass alle Körper für dasselbe durchlässig sind, aber in sehr verschiedenem Grade. Einige Beispiele führe ich an. Papier ist sehr durchlässig; 4 hinter einem angeblenden Buch und ca. 1000 Seiten sah ich den Fluorenenstrahl noch deutlich leuchten. Die Itrkerschwärze bietet kein merkliches Hindernis. Ebenso zeigte sich Fluorensens hinter einem dungenen Whirlstiel eine einzelne Karte zwischen Apparaten.

1) Mit Durchblauigkeit - aus dem Körper bezogene ich das Verhältnis der Heiligkeit sowie nicht hinter dem Körper gehaltenes Fluoreszenzverhalten zu derjenigen Heiligkeit des Schirms, welche denselben unter denselben Verhältnissen als eine Leuchtverhüllung des äußeren saugt

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Courtesy, Prof. A. R. von Hippel of M.I.T.

The first Röntgen Announcement

Only seven weeks lay between the discovery of X-rays and the submission of the first report by their discoverer. A few days more were required to prepare and publish the epochal 10-page announcement under the title "A New Kind of Rays". The first page of the manuscript and the cover of the first printed announcement are shown. Also, the first page of the copy that Röntgen sent to his friend von Hippel. Röntgen wrote, "Sent to you to indicate what the truth is, and what the damn papers dreamed up."

tion-coil and was covered by a black cardboard envelope, and the whole apparatus placed in a dark room, a bright illumination would be observed during the discharge if a paper screen coated with barium platinocyanide was placed in the vicinity of the coil and tube. Either side of the screen might be turned to the tube with equal effectiveness. The black envelope, opaque to visible light or ultra-violet rays from the sun or from an electric arc, would not filter the rays of the tube upon the screen.

Having established the existence of these new rays, Röntgen called them "X-rays" to distinguish them from other rays already known. He then noted that even a bound book of a thousand pages offered little resistance to the emanations upon the screen and that even the cumulative effect of the printer's ink made little difference to the penetrating qualities of the rays.

A playing card interposed showed no presence and a double pack of playing cards created little resistance to the beam. Similarly, a single sheet of tinfoil was hardly observable and only the addition of several layers began to show a distinct shadow upon the screen. Pine boards three cm. thick remained partially transparent to the rays. The behavior of glass remained a special phenomenon because, altho generally transparent to visible light, the amount of lead contained in the glass showed up markedly on the screen. Finally, and most dramatically, the shadow of the hand with its relatively transparent fleshy parts and darker shadows of the bones produced a stark image.

Various substances—gases, liquids or solids—were shown to be as transparent as air. Sheets of copper, silver, lead, gold and platinum showed transparency of differing degrees, with platinum

partially transmitting the fluorescence up to a thickness of 0.2 mm. Lead of 1.5 mm. was practically opaque and therefore lent itself to experimental work by the contrasts that showed up on the photographic plates. A wooden rod 20 mm. square in section and painted on only two opposite faces offered no hindrance to the X-rays when the painted surfaces were set parallel to the beam, but showed as a dark streak on the plate when the stick was turned with the painted faces across the beam.

With so many variables, Röntgen attempted to relate transparency to some simple property, such as the density of the substance. He therefore examined plates of glass, aluminum, calcite and quartz, all of about the same thickness, but found that the variations did not correspond exactly to density. Later analysis seemed to indicate that transparency to the rays varied inversely as the molecular weight of the substance. Uranium of atomic weight 240 was found to be most opaque while lithium, with atomic weight of only 7 (and therefore able to float on water), was shown to be exceedingly transparent.

Röntgen observed that barium platinocyanide was not the only substance that fluoresced when exposed to X-rays; he also listed calcium compounds, uranium glass, ordinary glass, calcite, rocksalt, etc. He regarded it as fortunate that photographic dry plates were sensitive to X-rays; with these a measure of relative ray intensity was established and demonstrated. Simply wrapping the photographic plate in heavy black paper or its usual photographic plate holder enabled Röntgen to perform his experiments in daylight. On the contrary, it was no longer possible to leave wrapped photographic plates lying about the laboratory exposed to incidental X-rays generated nearby, for this would spoil them. It was by means of photographic prints that Röntgen was able to quickly transmit the substance of his discovery to other scientists in Germany and abroad.

As a physicist, Röntgen was concerned with

the various possible manifestations of the X-rays. In his initial announcement of December 1895, he indicated that he had not tried to determine any generation of heat by the X-ray other than the observed fluorescence. He also recorded that that eye's retina was not sensitive to the emanations. He regarded nothing in the eye structure itself to obstruct or absorb the rays.

Refraction and Reflection

Yet another experimental line of approach was to attempt to refract the new rays by the use of prisms having a 30° refracting angle and consisting of mica sides filled with water or carbon disulphide. No deviation of the rays was observed altho a very slight angle seemed to have resulted when prisms of hard rubber or aluminum were tried. Attempts with denser materials failed to permit the passage of the rays from the comparatively weak source of generation then available to him. This was to be the line of attack by physicists all over the world for the next 20 years and was to lead to the modern revolution in physics.

Röntgen hit upon an approach to determine qualitatively whether X-rays were refracted or reflected by various substances. He subjected the X-rays to mass action by using the equivalent mass of solid material in powdered form, so as to multiply any deviation. He tried finely powdered rock-salt, silver powder and zinc dust, but could observe no difference between the transparency of the powdered mass and that of the solid substance as shown either upon the fluorescent screen or registered on the photographic plate.

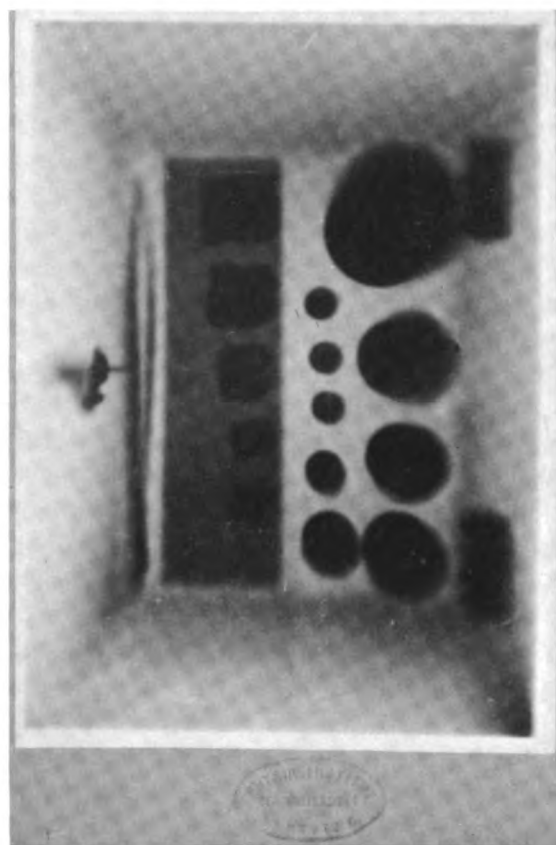
Röntgen next tried to concentrate X-rays with the use of lenses. He introduced large lenses formed of hard rubber into the X-ray's path with no visible increase in concentration. Glass lenses proved no better. He next tried placing cylindrical rods across the path but no more than the usual darkening along the axis (in the ratio of

increased mass) was indicated in the shadow-graph. When he photographed a tube filled with some substance, it cast a shadow lighter in the middle than along the edges.

Reflection, on the other hand, was thought unproved except in one experiment where it might seem to have been demonstrated by Röntgen. He wrapped a photographic plate in black paper, facing the glass side towards the discharge tube. He then placed a composite sheet in the form of a star in which one section was of platinum, another of lead, then zinc and aluminum. The star was pressed against the black paper on the emulsion side of the plate and then the plate was exposed to X-rays. When developed, it was seen that a pattern of various dark-nesses appeared under the platinum and the lead, a particularly dark area under the zinc, whereas no pattern appeared under the aluminum tine.

The conclusion then seemed obvious, that the first three metals reflected the X-rays whereas the aluminum transmitted them. Röntgen was aware that there might possibly be other explanations for the darkening of the platinum, lead and zinc areas and therefore hit upon a confirming experiment. He added a thin sheet of aluminum between the star pattern and the emulsion on the theory that if ultra-violet rays were the cause of the darkening of the film, the aluminum sheet would be opaque to these rays but would be transparent to the X-rays. He found the result to be the same as without the aluminum foil and therefore could rule out ultra-violet rays as a factor, and conclude that the darkened areas of the plate truly were caused by reflected X-rays from the three metallic plates. This contradiction awaited further experimenting.

In a subsequent series of experiments he also confirmed what he had expected—that the X-ray intensities followed the inverse square law in distances between the point of ray generation and the screen. He also demonstrated that fluorescent glow was visible as far as two meters from the discharge tube.



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A Röntgen Radiograph

One of the first X-ray photographs sent by Röntgen to his colleagues to demonstrate the new ray was part of a set of metal weights contained in a closed wooden box. It bears the stamp of the Physical Institute of the University of Würzburg, where the discovery was made.

In his report Röntgen discussed a series of experiments to demonstrate the difference in behavior between his X-rays and the cathode rays described by Lenard. The former had far greater penetrating power and, unlike the cathode rays, were unaffected by even a very intense magnetic field for Röntgen observed no magnetic deflection. If, he stated, the source of X-ray radiation was to be considered as that spot on the discharge tube where fluorescence was strongest (where the cathode rays struck the glass wall of the tube), then the shifting of the cathode ray

by a magnet would also shift the X-ray source to the new terminus (or anti-cathode) of the cathode rays.

Röntgen then reviewed the various photographs taken with his apparatus to demonstrate the true "ray" character of the emanations. The most dramatic were photographs of the hand showing the bony structure, a photograph made thru his laboratory door which registered the varying thickness of stiles and panels and especially the streaked areas made by brushing on lead-based paint. One radiograph showed the shadow of a wire wrapped around a wooden spool, another was a shadowgraph of weights set in a covered wooden box. Still another clearly showed the needle and degree markings of a compass in its enclosing metal case.

Realizing the conflict between the urgency for announcing such an important discovery* and the need to test all physical characteristics of the new rays, Röntgen added that he regretably had not yet determined interference phenomena of the X-rays nor their electrostatic forces, altho starts were made in both of these investigations. He was also aware that the penetrating power of his apparatus was still in an early and therefore comparatively weak stage.

Finally, Röntgen discounted X-rays as being ultra-violet rays because they were not refracted in passing from air into various substances, such as water, carbon disulphide, aluminum, rock salt, glass, zinc, etc., nor were the rays reflected

by them. Further, X-rays were not polarized, as were ultra-violet rays. He speculated that the newfound rays might represent longitudinal rather than transverse vibrations in the ether and that this opened up the need for a new chain of experiments.

The announcement is made

Altho this report came during the active holiday season, it was immediately set into print and distributed during the very first days of January 1896. Within a month the full text was translated and published in England and within six weeks in America. After a few more weeks it appeared in French, Italian and Russian.

Edition followed edition in quick succession so that in the first few weeks after the announcement, five editions in the original format rolled off the German presses. Not only did these quickly carry the description of the new discovery to the main centers of investigation, but Röntgen dispatched copies of the early X-ray photographs to his friends in Vienna, Berlin, Hamburg and Manchester. After the earlier work of Hittorf and Crookes on the application of high voltages to vacuum tubes, it was fairly simple to repeat and confirm Röntgen's basic experiments. The spark kindled in Würzburg was therefore fanned into brilliance in many laboratories immediately after the announcement. Not only physicists but anatomists and

*The bibliography of this classic of science was treated by Dr. Ernst Weil of London in *ISIS* for November 1938, page 362, as "Some bibliographical notes on the first publication on the Röntgen Rays". This followed facsimile reproduction and notes by George Sarton in the March 1937 issue of *ISIS*, pages 349-369. The manuscript of the first of three parts of Röntgen's paper was received by the secretary of the Institute for Physics of the University of Würzburg on 28 December 1895 and published immediately as a separatum in January and in the *Proceedings of the Physical-Medical Society* in Würzburg for the end of 1895, pages 132-141. During 1896 this paper was reissued four times. A continuation of the paper appeared in March 1896 and the third and final part was submitted in March 1897. Reprints in the original

German appeared in Würzburg in 1915 (all three parts) as a tribute to Röntgen on his seventieth birthday. They were again republished in Leipzig in 1954, in Stuttgart in 1959 as a memento of the IX Congress of Radiology, and also in Otto Glasser's *Röntgen*, Berlin, 1959. English translations were first made by Arthur Stanton in *Nature*, London, on 23 Jan. 1896, by Dr. William J. Morton in New York (first part only) in 1896, and by George F. Barker (all three parts) also in New York in 1899. The last of these was used by Glasser in his English *Röntgen*, London, 1933; it was freshly translated by him in his short version, Springfield, 1945, on the centenary of Röntgen's birth and the 50th anniversary of the great discovery. Finally, another fresh translation (first two parts) by Dr. R. Schlapp, was issued as *Alembic Club Reprint No. 22* at Edinburgh, 1958.

physicians immediately recognized the importance and value of this new instrument of diagnosis.

In a letter written by Röntgen shortly after his great discovery to his former pupil and assistant, Dr. Ludwig Zehnder, then professor of physics at the University of Basel, he gave the clearest account of the event: "Of what nature the rays are is not quite clear to me and whether they are really longitudinal light rays is only of secondary importance to me. The most important thing at this time are the facts. In this respect my work was appreciated from many sides. Boltzmann, Warburg, Kohlrausch, (and last but not least) Lord Kelvin, Stokes, Poincaré and others expressed their appreciation and their pleasure about the discovery. I value this greatly and appreciate their recognition; let the envious ones chatter all they want; it's quite the same to me. I haven't told anybody about my work. I just told my wife that I was working on something about which the people, after they would be told about it, would say 'Röntgen apparently has gone crazy'. On January first I sent out the offprints and then all hell broke loose! The press in Vienna was the first to blast the trumpet to the world and the others followed. After a few days I was disgusted with the whole thing. I could not even recognize my own work on reading the reports. Photography was only a means to me and yet this was made the main discovery. Slowly I got used to all the racket, but the storm cost time; I could not do a single experiment for four full weeks. Other people could work—but I could not. You have no idea what went on."*

From Mrs. Boveri we learn something of the tension that haunted Röntgen during his earliest recognition of the unexplained phenom-

enon. He had written to her on 11 November 1920, "I do not believe that I made a note when I observed the X-rays for the first time; in Munich there is the first photograph of a hand—Bertha's—and perhaps you'll allow me to send you a copy of it." Mrs. Boveri, one of the best friends of the Röntgens', related, "In telling about the circumstances which followed the discovery, Mrs. Röntgen said that she had to go through several terrible days. Her husband came late to dinner and usually was in a very bad humor; he ate little, didn't talk at all, and returned to his laboratory immediately after eating. He didn't reply when asked what was the matter. Röntgen answered this story of his wife's by saying that, when he first made the discovery of the penetrating rays, it was so extraordinarily astonishing that he had to convince himself over and over again that they existed, by making repeated observations, before he was able to accept the phenomenon himself."*

The X-ray photograph of a living hand was so startling, eerie and yet informative, that journals or opinion as well as technical journals immediately reproduced them with whatever comments the journalists could put together. Hands with rings on the fingers, others holding bouquets of flowers, some with broken bones or amputations, were photographed. In January 1896 a photograph was made in Paris of a hand with a bullet in it and during the next month other plates were exhibited at many lectures and in a dozen publications.

Excepting the German experimenters, the greatest activity in repeating and expanding on Röntgen's disclosures occurred in England, where Kelvin had received a photograph of the original hand in the last days of 1895. There A. A. C. Swinton photographed a number of subjects, some of which were reduced to lantern slides for lecture purposes. Especially popular was an X-ray of a frog showing exceptionally

*ZEHNDER, Ludwig, *W. C. Röntgen Briefe an L. Zehnder*, Zürich, 1935, page 39. Zehnder was Röntgen's assistant for seven years and the recipient of over 160 notes and letters from him. He was named, with Prof. von Hippel, as executor of Röntgen's will, but both were later replaced by Röntgen's best friends, Mrs. Margaret Boveri of Würzburg and Dr. R. Cohen of Munich.

*GLASSER, page 129.

fine bone details. J. J. Thomson, experimenter with electricity-in-gas phenomena, thereupon extended his research into X-rays.

One of the earliest accounts of the receipt of news of Röntgen's discovery was related by Arthur Schuster. During the first few days of January 1896, he had received a flat envelope containing photographs of the skeletal hand, with no explanatory enclosure other than the first Röntgen pamphlet. "This was the first authentic news that reached England of a discovery made at the end of 1895, which both directly and indirectly gave tremendous impulse to experimental science. Before I left the room, and although my family was waiting for me in the cold outside, I had read and reread Röntgen's account, which concisely but convincingly described the experiments, by which he had with remarkable ability, investigated and determined the main properties of the new radiation."*

The aftermath

Demands on the manufacturers of electrical apparatus that could be used in X-ray technology were so great that production schedules were forced ahead for months. Instrument makers, coil winders, glass blowers were sought out and burdened with requests for induction coils, tubes, interrupters and screens.

Among those who had second thoughts after the Röntgen announcement (remembering that they also had noticed fogging of photographic plates that had happened to be in the vicinity of activated vacuum tubes), one may count not only Crookes who had complained of faulty plate-making by the manufacturer, but also an unnamed English scientist mentioned by Lord Rayleigh who, when he found his plates were being fogged by activated vacuum tubes, decided that he had better store them elsewhere.

*SCHUSTER, Arthur, *The Progress of Physics During Thirty-Three Years*, Cambridge, 1911, page 73.



Hand des Anatomen Geheimrath von Kölliker in Würzburg.
Im Physikalischen Institut der Universität Würzburg
am 23. Januar 1896 mit X-Strahlen aufgenommen
von
Professor Dr. W. C. Röntgen.

Vorlag der Strahlenk. Hof- und Universitäts-Buch- und Kunsthandlung in Würzburg

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First X-ray made in public

So great was the clamor to learn about X-rays that, following a demonstration before the Kaiser in Potsdam, Röntgen gave only one public presentation describing his discovery. At a packed session at the University of Würzburg on 23 January 1896, he radiographed the hand of his colleague, the anatomist von Kölliker, developed the plate and showed the result to the entranced audience. The above print was made from the negative.

Just as the incidents of excitement and journalistic activity were high, so also was the saturation point quickly reached, and the general interest began to wane. However, the shock of one looking at a shadowgram of his hand, or one of his head picturing mainly the hollow-eyed

skull, produced such sensations of having seen "his own death head" that only the scientifically curious grasped the importance and potential of this new instrument of investigation. The fearful ones saw invasions of privacy. The rhymesters had their inning too, such as the verse of five stanzas that appeared in *PUNCH* on 25 January 1896:

*"Oh, Röntgen, then the news is true,
And not a trick of idle rumour,
That bids us each beware of you.
And of your grim and graveyard humour."**

The cartoonist and joker saw in the new device an end to old problems and crimes and the beginning of a new set. As it was food for the wit, so the guardians of public morals rose to the occasion. A legislator in New Jersey introduced a bill "Prohibiting the use of X-rays in opera glasses in theaters".**

The first demonstration of the discovery of X-rays by Röntgen was on 13 January 1896 when Röntgen, on the invitation of Kaiser Wilhelm II, journeyed to Potsdam to demonstrate the new discovery. From five o'clock that evening until midnight, Professor Röntgen was in the company of the Kaiser and members of the court. There was a demonstration with rather limited equipment in which the new rays were shown to penetrate boards of paper and wood, pass thru boxes and various other objects, but not the living hand. Röntgen dined with the Kaiser and their conversation continued into the night. The Kaiser, in a simple ceremony, decorated him with the Order of the Crown.

The only public lecture

The first public demonstration before a scientific body occurred on the night of 23 January 1896 when Röntgen addressed the Würzburg

*GLASSER, page 41.

**GLASSER, page 45.



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Hand of a scientist

At a demonstration of X-rays at the Royal Society on 6 May 1896, the hand of Lord Kelvin was radiographed by Campbell Swinton. His approval was indicated by his signature.

Physical-Medical Society before this select but large and crowded audience. Every official, academic, military and professional body wished to be represented at such an important demonstration so that the hall filled early and was tense until Prof. Röntgen appeared. The applause that greeted him was stormy and was repeated several times during the demonstration that evening. With genuine modesty Röntgen first gave credit to his predecessors in the investigations of cathode rays, mentioning Hertz, Lenard and Crookes in particular. He then related the course of his own experiments, his observation of the glow on the sheet of paper covered with barium platino-cyanide when exposed to a Hittorf-Crookes tube that had been enveloped in a cardboard casing.

He then indicated that by a series of investi-



Early X-ray of a hand

One of the clearest of the early class of radiographs was published by David Walsh, M.D. of London in his book on *Röntgen Rays in Medical Work* in 1897. The fingerprints are clearly visible.

gations the source of the fluorescence narrowed to the discharge tube and that even when the treated paper was moved a considerable distance from the tube it still glowed faintly. When he realized that he was in the presence of rays that penetrated black paper, he turned to other materials such as wood, cardboard and even books, all the time remaining incredulous and fearing himself to be a subject of some incomprehensible deception. He finally fixed his observation upon

photographic plates, subject to comparison, analysis and examination, and only then did he realize that he was actually grappling with a hitherto unknown phenomenon.

After his introductory review he proceeded to demonstrate by experiment the penetrating power of the X-rays upon paper, wood and tin. He then turned the apparatus upon his own hand and showed the effect. He also showed that by introducing a leaf of platinum a complete shadow was cast, indicating opacity to the X-rays. When he finished his lecture, the directness, clarity and simplicity of his remarks brought thunderous applause from the crowded audience.

Following his formal presentation of the main facts relating to his discovery, Röntgen invited a colleague at the university, the anatomist and embryologist, Prof. R. A. von Kölliker, to have his hand photographed by the new rays. This was done, the plate was developed and then shown to the audience amid a burst of applause. Von Kölliker added some remarks noting that, in his 48 years of affiliation with the Society, he was now witnessing the most important disclosure in the field of natural science and probably in medicine. He then called for a round of cheers for Röntgen and proposed that the new rays should henceforth be designated as "Röntgen rays".* By unanimous and enthusiastic applause, the proposal was approved. Altho Röntgen lived 27 years longer, this was the only formal lecture given by him on the subject of the discovery of X-rays.

As so often happens in the case of a great discovery (Columbus and the egg), the disclosure by Röntgen of his epochal discovery brought out two sets of commentaries from his fellow scientists. The first was from the experimenters with cathode ray apparatus who had come close to recognizing the next stage in the evolutionary

*The designation of "X-rays" by the discoverer continues to remain the most common name for the new penetrating rays. However, most German sources prefer to honor the discoverer by referring to them as Röntgen rays.

process of vacuum tube discharges, but failed to do so. The other shrill voices to be heard came from those who provided slight improvements to Röntgen's apparatus or extended his delving into the many new fields that were now opened up, but who made it sound as tho the importance of the improvement exceeded the explicit work of Röntgen. What Röntgen had arranged, as far as apparatus was concerned, others had done; what he saw issuing from the apparatus was what others had missed. Prof. Hugo Münsterberg of Harvard, writing from Freiburg on 15 January 1896 to *Science*, stated, "Suppose Chance helped. There were many galvanic effects in the world before Galvani saw by chance the contraction of a frog's leg on an iron gate. The world is always full of such chances, but the Galvanis and Röntgens are few."*

Having observed a phenomenon that was both novel and inexplicable by the knowledge of his time, Röntgen, trained in a tradition of sound skepticism and thoro care in experiment, faced a prime problem much in the spirit that Faraday did when the gleam of the proper approach to magneto-electric induction crossed his mind. In both of these master experimenters lay the conviction that nothing was so thoroly proved as a well conceived and carefully executed series of demonstrations.

Just such a chain of experiments was outlined in his first communication to the Würzburg Society. The succinct brevity, the quiet objectivity, the carefully planned approach and the confidence of the conclusions all reflected the attack of a disciplined mind upon a problem of science. There must have been deep misgivings and concern over faulty procedures, hasty inferences and the usual chances for error. Confirmation and reconfirmation was the inevitable routine, and Röntgen followed thru. He faced the risks of anticipation by others yet unknown to him, the probable ridicule for over-zealous

conclusions and claims, and finally the fear that something somewhere was not what it seemed to be. Procrastination was not in Röntgen's character. Having followed the logical sequence of analysis, experiment and confirmation, he risked announcement and publication. The world was prepared to see and listen.

Röntgen was also the happy combination of one skilled in the mechanical art of fabricating equipment with his own hands, and in mathematical analysis, when required. Having been forced actually to build and assemble apparatus in the old Würzburg Physical Cabinet, he had acquired the ability to visualize both structure and performance of the equipment in correspondingly sharper terms.

In the days when experimental apparatus was comparatively simple and could readily be assembled by a single operator, Röntgen preferred to assemble and connect his own equipment and to make his own observations. This may have been the result of the initial circumstances where he could not be provided with assistants for budgetary reasons or, more probably, out of a personal preference for solitude and self-dependence. He therefore disregarded the clock and, again like Faraday, worked at an intense pitch when a pressing investigation had to be followed. Handicapped by impaired vision in one eye and by color blindness, there were times when assistance was needed, as when simultaneous readings were necessary. In general, his preferences were strongly for solitude in work and gregariousness at play with friends and family.

In the early 1900s, when many academic offers were thrust upon him, he turned to the great mathematical physicists of the time—Lorentz, Sommerfeld and von Laue—for counsel on filling the growing number of vacancies in professorships of physics. As early as 1907 he concerned himself with Einstein's theory of relativity. In 1888, probably influenced by the Michelson-Morley experiments on ether drag

*GLASSER, page 73.

of a year earlier, he worked to measure a possible magnetic effect of the ether wind moving thru a condenser as it revolved in the earth's motion.

X-ray experiments everywhere

On the release of his first report the news of the discovery spread quickly into every corner of the world where any scientific or cultural interest existed. Not only was this discovery in itself an astonishing, bold and powerful tool released to the inquiring mind, but there also was breadth of interest because here was a means of probing the very body of every living being. A discovery of such universal magnitude is rarely attained. The mere thought that a new process had been devised that could see thru solid physical objects prompted everyone to regard it as a marvel indeed. This Röntgen must have sensed, for in spite of his valiant effort to continue his research in the isolation and quiet upon which he insisted, his remark to his wife, "it will now be the devil to pay!", reflected his awareness and concern.

Even after his first publication, so many unanswered questions remained that he persisted in his investigations despite the attention paid him by those ready to impose honors, request interviews, consult the famous or solicit prophecies. He therefore packed the first two months of 1896 with intense concentration and great energy in the preparation of his second communication. Peace had fled, the interruptions were numerous and the unwelcome visitors continued in a constant stream.

An observer would sometimes be invited to enter the booth, close the door and in the complete darkness hang a fluorescent screen opposite the disc. Röntgen would then excite the induction coil, raise the induced currents to generate the sufficient order of cathode rays to cause the yellow-green luminescence to appear upon the screen and then invite the visitor to

interject objects of varying kind and thickness between the disc and screen. A two-inch thick book made little difference upon the fluorescent pattern that rode like moving clouds over the screen. Looking into the rays created no sensation on the retina of the eye. Actually it was reported later* that if one gazed at X-rays for a few minutes after having sat in total darkness for 30 minutes, a faint fluorescence was discernible on the eye's retina. A small lead object placed before the eye could also be discerned. If one had a cataract but an unimpaired retina, the object would also be seen, but upside down, because the focusing power of the human lens would be ineffective to X-rays.

In spite of Röntgen's robust health and high capacity for work, his wife expressed concern over the strain to which he was subjecting himself and was being subjected by others. Beyond doubt, his dedication to the task before him and his modesty kept him from the distractions that have plagued those more vain or weak. He kept his contacts to a minimum, and the statements he made, such as his lecture before the Physical-Medical Society of the University on 23 January, were always crisp, modest and limited to the substance of his first paper.

The national enthusiasm for the great discovery was so high at the time that the president of the Reichstag invited Röntgen to present a demonstration not only to the national legislative body but also to the Bundestag in Berlin. Röntgen declined the invitation but another physicist, P. Spies of Berlin, lectured before a packed Reichstag audience on 30 January. Other invitations flooded in and were also declined, but with such comparatively simple and well known apparatus, demonstrations were made by other lecturers. So distasteful to Röntgen were the many offers to honor him that he sought refuge from the invasion of his privacy by arranging a trip to Italy in March.

*GARLAND, L. Henry, "Scientific Importance of X-Rays" in *Electrical Engineering*, December 1945, page 437.



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Dr. Wilhelm Conrad Röntgen

The immediate recognition of the great value of his discovery of X-rays brought to the modest professor the acclaim of the world of science. He received the first Nobel award in physics. This photograph was taken in 1906 while he was director of the Institute of Physics in the University of Munich.

Wirkung übergl.

Hochgelehrter Herr Professor!

*Bitte mir gütigst zu versetzen, dass ich Ihnen nur per
Postkarte kurz auf Ihren letzten Auftrag vom 5. d. M. antworte.
Leider gestattet mir meine Zeit nicht irgendwas über meine Arbeit
ein Wort zu schreiben; die ein beim Kaiser, die andere in der Kaiserin
Phys. med. Gesellschaft sind die einzigen gewesen. Ich bedauere damals
Ihren Wunsch nicht entgegen zu kommen.*

Hochachtungsvoll

Dr. Röntgen

W. Röntgen

Röntgen declines to lecture

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This note, dated 9 February 1896 to Prof. Schrötter of Vienna, mentions Röntgen's only two lectures, one given in private to the Kaiser and the other in public to the Physical-Medical Society in Würzburg. He regrets having to decline further invitations.

Altho he declined many offers, he accepted a few, among them the honorary degree of Doctor of Medicine offered him by the medical faculty of his own University of Würzburg, in recognition of the importance of X-rays to the medical sciences. This honor was bestowed on 3 March 1896, just before his departure for Italy.

The sincerity of Röntgen's modesty was expressed when the Kingdom of Bavaria offered the Royal Order of the Crown to him. This carried with it not only the honor and decoration, but also personal nobility. Röntgen accepted the decoration but declined the status of nobility. He also declined to use the coveted *von*, a symbol of status in a most status-conscious nation.

As it was at home, so it was abroad. Offers of membership and awards poured in from foreign science societies. He declined membership in associations and academies but in November 1896 he did accept the Rumford gold medal of the Royal Society in London. Altho

he was distant to the fame hunters and maintained an alert vigilance against intruders, he remained exceedingly cordial to the simple people about him.

The second communication

A period of ten weeks separated the dates of the paper by Röntgen "On a New Kind of Rays" that was accepted by the Physical-Medical Society of Würzburg on 28 December 1895, and his second communication that appeared on 9 March 1896. During these very strenuous weeks Röntgen pursued new lines of investigation, answered inquiries by his colleagues, extended the design and construction of new apparatus, fended off the demands on him for time to lecture, receive honors and answer interviews. Most annoying was the incursion on his work by the curious, the vain and the ambitious.

In his second communication Röntgen reported that he had devised a scale for measuring the intensity of the rays by observing the degree of fluorescence on a screen or the intensity of blackening of a photographic plate. He also observed that electrified bodies in air carrying either a positive or a negative charge would be discharged if exposed to X-rays. Replacing air by hydrogen or reducing the air or the hydrogen pressure, he found that the rate of discharge was correspondingly reduced. At the time of his first publication, Röntgen stated that he was aware that X-rays could discharge electrified bodies and held that in the experiments of Lenard it was X-rays and not cathode rays which had penetrated the aluminum window of his discharge tubes; now, he had performed additional experiments to confirm this.

Röntgen recommended the insertion of a Tesla arrangement of condenser and transformer between the vacuum tube and the induction coil. Such an addition, he stated, would provide the advantages of generating less heat and maintaining the vacuum for a longer period, and would generate a more intense penetrating beam. It also served as a compensation for vacuum tubes that had been too much or too little exhausted.

A refinement to the tube construction that preceded the Röntgen discovery was the suggestion by both Hittorf and Crookes for regulating the vacuum within the tube. The diminution of gases in the tube after continued use produced a "hardening", which decreased the intensity of the X-rays but increased their penetrating ability. To maintain constant characteristics, they independently provided means for restoring small amounts of gas by fusing short auxiliary tubes to the main tube and into these was added a small quantity of potash or potassium hydrate, which was heated to emit small quantities of replacement gas.

Röntgen further announced that, in addition to the X-ray generating source lying in the sur-

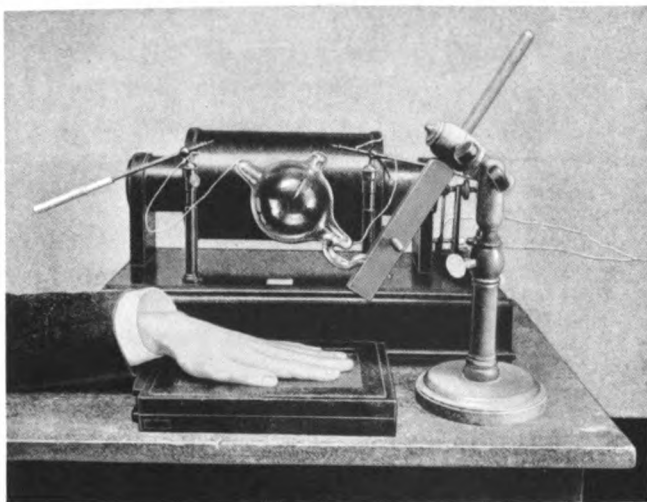
face of glass and in aluminum, he could confidently add that any solid body could be made to generate X-rays when cathode rays are directed upon it. In addition, he ventured to state that he knew no reason why liquids or gases could not be made to behave in the same manner. He noted the varying degrees of emission as the cathode rays struck different materials such as platinum and aluminum, as well as the effect of varying the thickness of different metals. Thru his experiments he observed that the most intense X-rays were produced from a tube in which the cathode was an aluminum concave mirror and the anode a platinum sheet placed in the focus of the mirror but inclined to the mirror axis at 45°. He found that, altho the X-rays emanated from the anode in this case, it made little difference in ray intensity whether the emanations were from the anode or from another point. The third section of his research into the properties of X-rays was submitted in March 1897, after which there remained a gap in publishing that lasted seven years.

Silvanus P. Thompson of a London university complained that "Röntgen had so thoroughly explored the properties of the new rays by the time his discovery was announced, that there remained little for others to do beyond elaborating his work."* One area of improvement was the replacement of the anti-cathode formed on the inner glass face with a metal reflecting plate. The best reflector was found to be uranium, with platinum next best, then other metals.

At Munich

After declining an invitation to fill the chair in physics at Leipzig vacated by the famed Wiedemann, Röntgen accepted the position to head the Philosophical Faculty of the University of Munich for which the Bavarian Government made a special appeal. This major academic

*THOMPSON, S. P., *Light Visible and Invisible*, London, 1897, page 264.



McClure's Magazine, May 1896

Exposing a hand to X-rays

A Rhumkorff induction coil supplied a pulsating current to the Crookes tube over the hand resting on a covered photographic plate holder. From an early popular account by an American surgeon.

change involved a move to Munich, a reorganization of the Physical Institute and a modernizing of the laboratory equipment. From Munich he issued only seven communications during a span of seventeen years, some in collaboration with his pupil A. Joffé. These covered investigations in pyro- and piezo-electric phenomena (a continuation of his former interest) as well as a continuing probe and support of the many investigations of the properties of X-rays which were undertaken in various laboratories.

Two honors of unusual distinction were accepted by Röntgen. In 1900 he received the Barnard medal which was awarded every five years by Columbia University at the recommendation of the American Academy of Sciences. The following year the first of the Nobel prizes were awarded, and that in Physics went to Röntgen. Unlike all other recipients of this great distinction, Röntgen did not give a Nobel lecture but, during the banquet which

followed the official presentation, limited himself to thanks for the honor he received. He promised to continue scientific research that might prove of benefit to humanity. He expanded on this purpose when he returned to his flower-laden desk at Munich by emphasizing that the true rewards of accomplishment lay not in honors and recognition but rather in the joy of accomplishment itself. To underline his strong sentiments in the matter, he bequeathed the Nobel prize money of fifty thousand Swedish kroner for scientific research at the University of Würzburg, seat of his immortal discovery.

After the first announcements appeared in the public press, several attempts were made by commercial organizations and entrepreneurs to exploit the commercial possibilities of the new rays. Röntgen stood by the principle that a professor's life and contributions were dedicated to the public good. He therefore sought no patent on his discoveries or copyright on his publications or any photographs that he took.

Subsequent to his rise to the highest order of fame, Röntgen pursued his investigations tirelessly as he had thru his mature life with the same thoroughness of organization, attention to the minutest detail, measurement and observation, and the same sound presentation at his lectures. If anything, his new responsibilities forced him to be even more cautious and thorough in the statements he made and the conclusions which he drew. He asked as much from the graduate students at his Institute, for he was a hard and strict taskmaster, but he demanded nothing from others that he himself was not prepared to do.

As the use of X-rays spread thruout the civilized world, their application as a research tool widened and new discoveries were inevitable. In 1905 a group of physicists including Boltzmann, Lorentz and Planck united to honor Röntgen on the tenth anniversary of his discovery and to place on the Physical Institute of the University of Würzburg, where the discovery

was made, a marble plaque bearing the words, "In this building, W. C. Röntgen discovered the rays which are called by his name." Thus the pride and respect of his eminent colleagues were shaped into this simple statement.

As the distractions of his new position in the community and nation multiplied, his contacts with the outside world became more formal. He declined two invitations to head the foremost physics institutions in Berlin. Further, the health of Mrs. Röntgen began to fail. In 1912, Röntgen had indicated to his relatives in America that he was considering a visit there. However, the Great War exploded and because of his long residence outside of his country, he readily sensed the catastrophe that lay ahead.

His national feelings remained ever strong and when the call for gold was made to continue the war, he turned in his gold decorations, including the Rumford medal of the Royal Society of England, to be melted into bullion. This he later regretted. Röntgen was persuaded by some patriotic colleagues to sign a proclamation of ninety-three intellectuals in an "appeal to the civilized world" not to believe the reports of German excesses in the First World War. Later, in his older and calmer years, he regretted that he had permitted himself such involvement. He wrote to his friend Boveri, "The other day I received a pamphlet from a Belgian scientist which was somewhat embarrassing to me, especially because it referred to the well known proclamation of the ninety-three intellectuals which I, along with others, foolishly signed without first having read it, at the insistence of the Berliners."*

A significant honor was paid Röntgen at the end of World War I at a special gathering of the Prussian Academy of Sciences on 22 June 1919, honoring him on the occasion of the 50th anniversary of his receipt of his degree of doctor.

Among the laudatory remarks addressed to him at the meeting, it was stated, "The eminent practical significance of the new rays which you recognized at once but which you, in your noble unselfishness, have left to others to develop practically, was revealed in a most striking manner during the World War. One can say with complete authority that the fruits of your scientific investigations have spared life and limb to hundreds of thousands of poor wounded soldiers, both friend and foe. Thus you are not only esteemed by physical science as its immortal master, but also by all humanity as its benefactor."*

With the collapse of the German armies came bitter political unrest, a communist city government in Munich and the apparent spectre of inflation. Those with fixed incomes, Röntgen among them, suffered most, so the struggle to adjust to a daily rise in costs caused deep concern and actual privation to him. To add to his sorrows, within the year after the armistice Röntgen lost his wife and thereafter became increasing lonely.

The postwar years

He retired from his post as professor of Physics early in 1920 but two laboratory rooms were set aside for his continued use. A pleasant interlude during the postwar adjustments in Germany came to him when he accepted an invitation of a Swiss friend to visit once again that peaceful land. During the summers of 1921 and 1922, Röntgen again donned his heavy boots and wandered thru the mountain lanes, refreshing his spirits at the sight of the snowcapped peaks, the edelweiss and the roaring brook. He once wrote, "I still prefer to leave the well-worn paths, and to hike over stick and stone. I've already told Ritzmann, if ever I should be missed, not to look for me on the main road."**

*Quoted by GLASSER, Otto, in *The Scientific Monthly*, Sept. 1937, page 13.

*GLASSER, page 88.

**GLASSER, page 194.



Inflation Money, Lennep

To pay for the heavy burdens of war, the German nation, states and towns issued money of increasingly inflationary value. This note, issued in July 1921 by the town where Röntgen was born, also shows his birthplace.

In postwar retirement, Röntgen continued his interest in the advances in theoretical and experimental physics that flourished anew after the exertions of the conflict. In a letter written in 1921 he marveled at the report that Millikan in America had at his disposal \$100,000 a year for scientific research. He also pleaded for simpler and more verifiable investigations and found it difficult to justify the large laboratory which Einstein had created in Berlin to determine whether there was a shift in the red portion of the sun's spectrum as compared with the spectrum from artificial light, in order to confirm or disprove the general theory of relativity. He similarly could not attach the same importance as others did to confirming the shift of the perihelion of Mercury as well as the deviation of stellar light rays from their straight course as they passed by the sun. Yet he allowed for the enthusiasm of more youthful experimenters, especially those in America, who were encouraged by the work of Prof. L. Franck* of Göttingen in his investigation of the excitation of light by electronic impact.

At the beginning of the year 1923 Röntgen was still able to walk to the laboratory, eager to complete some experimental investigations which he had begun some months earlier. However he complained that walking was becoming more difficult and that his sight and hearing were proving inadequate for the observations required. On 10 February 1923 he died in Munich in his seventy-eighth year.

At his funeral there gathered members of academic institutions, the great museum in Munich, faculty colleagues and representatives of the city and nation. All acclaimed his genius, generosity and modesty. Then, in accordance with his will, his body was cremated and his papers and personal correspondence also given to the flames. His other belongings were auctioned and the proceeds turned to uses for education. Some of the personal property was distributed among his friends by his lifetime confidant, Mrs. Margaret Boveri.

Röntgen was an impressive figure, tall and lean with head always held erect. His boundless energy made it difficult to keep up with him on a mountain trail or with his long paces on the city streets. His thick dark hair, full beard and piercing eyes reflected an intense, direct personality.

Röntgen was known to exert the same strenuous pace at play as he did at his work. The steeper the mountain, the more difficult the passage, the better he liked it. In spite of the protracted illness of his wife, they managed many excursions into Switzerland, to the Italian Riviera and lakes and to Corfu. Sometimes, with the companionship of one of the younger members of a field party, he would cut across the landscape over hills and thru the woods. On one such adventure he slipped over the side of a cliff

*Röntgen probably was referring to Prof. James Franck, formerly at Berlin, Heidelberg and Göttingen, since 1935 Professor of Physics at Johns Hopkins University, and since 1938 Professor of Physical Chemistry at Chicago. A Nobel Laureate (1925), he joined the American group of physicists working on atomic energy in 1939.

and injured his head by striking a rock. His companion, the daughter of Theodor Boveri, kept the mishap a secret between them for the rest of his life. In the excitement of the mishap, the girl had lost her raincoat and the lame excuse for this served as an additional bond of secrecy between them. She, in later life, was one of the few privileged to provide notes for Röntgen's biography.

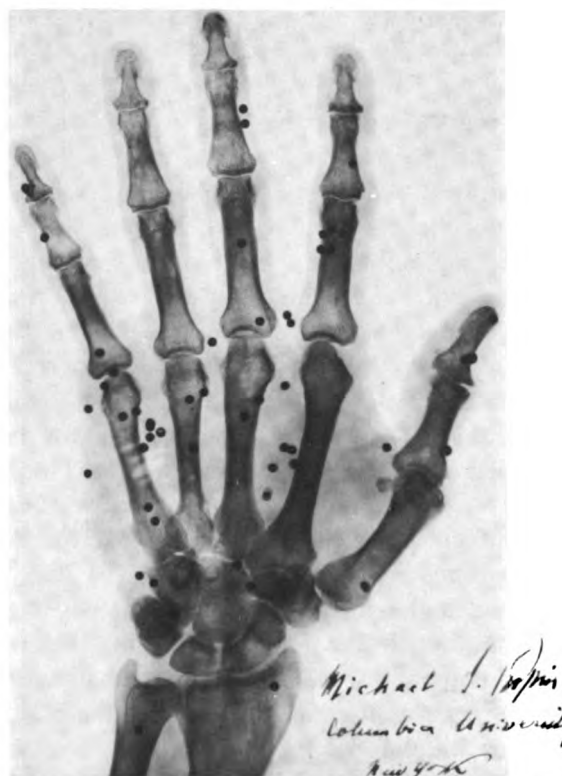
Even such strenuous activity as tobogganning down the icy paths in Davos, or hunting, pleased him greatly. He found pleasure and recreation by donning the gray-green hunting costume and the feathered hat of the Jaeger. The desire to hunt continued thru his years, and even at 70 he enjoyed wandering thru the forest, as much intrigued by sunset, sky and verdure as he was by the game. These woodland excursions also distracted him from thoughts of the war.

As his friends were few in number, so did he hold them in the highest regard. When Theodor Boveri was in his final serious illness in a sanitarium, Röntgen permitted himself the rare occasion to leave his ailing wife in Munich to visit his friend in Würzburg. On another occasion he sent a letter saying, "I found a bottle of sherry in my cellar and it is said that its contents are exactly as old as I am. At any rate when I bought the bottle in Würzburg the wine was 50 years old according to the label. I have sent you this contemporary of mine today with the hope that it will contribute its share towards making you feel stronger. If it does that, then the 'old hermit' will have done something useful."* When Boveri died in October 1915, Röntgen made one of his rare public statements at the cremation of the body of his friend.

X-rays abroad

The world first heard of Röntgen's discovery when a cable was issued from London on 6

*GLASSER, page 166.



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Gunshot in the hand

Prof. Michael I. Pupin of Columbia University first heard of Röntgen's discovery directly from a German physicist friend. He immediately set up the equipment to perform X-ray experiments and, in the first days of February, 1896 was asked to radiograph the hand of a New York attorney accidentally shot. The above, signed by Pupin, is one of the earliest records of the aid to surgery made possible by the invisible rays.

January 1896 which read, "The noise of war's alarm should not distract attention from the marvelous triumph of Science which is reported from Vienna. It is announced that Professor Routgen of Würzburg had discovered a light which, for the purpose of photography, will penetrate wood, flesh and most other organic substances. The Professor has succeeded in photographing metal weights which were in a closed wooden case, also a man's hand which shows only the bones, the flesh being invisible."

On the following day the Professor's name was properly spelled and with the passage of yet another day the notice appeared in the New York press. The source of the notice was given as Vienna because it was here that one of the photographs which Röntgen had dispatched to an old colleague had been exhibited and had come to the notice of a local journalist. A short summary of the meaning of the strange photograph appeared in the Viennese *Presse*, was thereby transmitted to German newspapers and then managed to reach England after a few more days. These early reports indicated that the Vienna professor, Franz Exner of the University of Vienna, a friend and former fellow student of Röntgen at Zürich, had actually received nine photographs which had been sent to him by Röntgen and was absolutely convinced of the authenticity of the marvelous claims. For the incredulous, the *Standard* of London had added, "The *Presse* assures its readers that there is no joke or humbug in the matter. It is a serious discovery by a serious German Professor."* To others the anatomical and surgical possibilities of such a remarkable aid were apparent.

Another friend to whom Röntgen sent the first X-ray pictures was Prof. E. Warburg, director of the Warburg Physical Institute in Berlin. The X-ray photographs were among the exhibits at the 50th Anniversary celebration of the Institute on 5 January 1896, but the speaker at the banquet failed to mention the presence of the pictures, and the opportunity of publicly introducing a discovery of the first magnitude slipped by.

Among the journalists who rushed to interview Röntgen in January 1896 was one from *McClure's*, an American periodical. In answering questions, Röntgen replied that he had been studying the problems of cathode rays in vacuum tubes by Hertz and Lenard but was anxious

to proceed on his own research. These he began at the end of October and on 8 November he first observed the effects of something new. He then described the phosphorescence of a piece of paper coated with barium platinocyanide lying on the bench near the tube. "And what did you think?" asked the reporter. "I did not think; I investigated."**

Many American journalists turned to the Edison laboratory in Orange, New Jersey, for more information (the more sensational the better) about the newly discovered rays. It was to be expected that the properties of the penetrating rays would arouse fad and fancy of extraordinary dimensions. Reports began to flow as to how a cheap metal had been transmuted, by application of X-rays, into certified pure gold. The new discovery was the very thing that the spiritualists, soothsayers, telepathists and clairvoyants were waiting for. A measure of the serious and sensational interest in the Röntgen rays can be drawn from the fact that during the single first year of the knowledge of their existence, 1896, more than a thousand books, pamphlets and articles appeared in the public press on this subject. The science and art of X-ray generation, emission, direction and control represented one of the most fertile periods of experimental ingenuity. The literature of this fecund period was vast and detailed.**

The earliest record of Röntgen's announcement to appear in this scientific press was in the *Electrical Engineer* of New York on 8 January 1896. This was immediately followed by notices in other scientific and medical journals under various headlines on both sides of the Atlantic. Before the month had ended, coverage of the

*GLASSER, page 200.

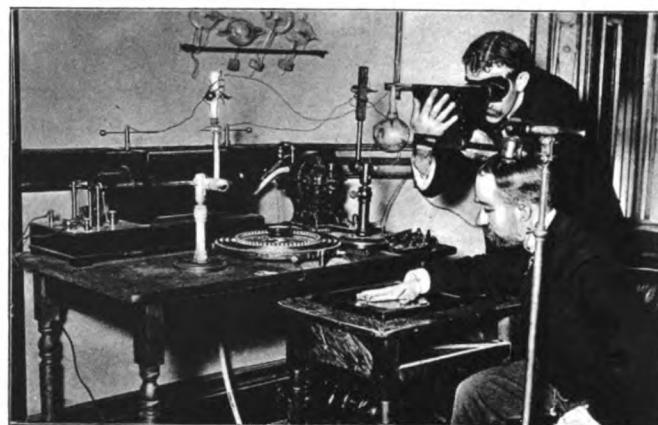
*DAM, H. J. W., "The New Marvel in Photography", in *McClure's Magazine*, April 1896, page 413.

**The flood of literature in this field is shown further by the publication of GOCHT, Hermann, *Die Röntgen-Literatur*, Stuttgart, 1911, listing over 10,000 titles, alphabetically arranged on 387 quarto pages. All this in only 14 years!

discovery had spread to every important center of science. Not only did the physicist, chemist and electrical investigator receive an important new stimulus in his field, but the physician, surgeon, anatomist and even the photographer were made aware that a new dimension had been added to their work.

The novelty and importance of the disclosure prompted further questions and discussion. Thus, in the first two months of 1896, X-ray topics appeared on the programs of important science academies. Societies especially dedicated to the search for and the report on X-rays were organized in several countries. The flood of papers and monographs began a crescendo that lasted for several years. In addition to those that genuinely contributed to the new science and technique, many papers just rode the crest of fashion and were simply a means of gaining attention or bolstering an uncertain reputation. The flood proved embarrassing to those who had made a genuine contribution because recognition and priority became dependent on the date of issue of a publication, rather than the date of discovery. The result was intense experimental activity with the establishment of priority as a primary motive instead of thoroughness of investigation. The German scientists found themselves at a special disadvantage because of their slower practices in publishing scientific journals. The already complex situation was even more strained by the urges of nationalism in judging values and assigning credit for improvements in X-ray technology.

Not only were special societies formed for the purpose of X-ray investigation and discussion, but special journals were established. The first such was founded in London in May 1896 as the *Archives of Clinical Skiagraphy* ("skia" is Greek for shadow). The success of this journal prompted a change of its name to *Archives of the Röntgen Ray*, and encouraged the establishment of similar journals in Germany, America and elsewhere.



Morton and Hammer, The X-Ray, New York, 1896

An X-ray laboratory in New York

Dr. William J. Morton, standing, tests the effectiveness of a Crookes tube by the clarity of the image of his hand upon the fluoroscope. The recommended five to fifteen minute exposure often resulted in severe radiation burns and subsequent amputation.

The many "anticipators"

After the publication of Röntgen's epochal paper, as might have been expected, there arose a chorus of claimants of priority in having observed the penetrating rays. The claimant usually concerned himself with some other form of radiation phenomena—Hertzian rays, high voltage electrical discharge, ultra-violet rays or cathode rays. The simple fact remained that if X-rays were produced (as they might have been) thru some other form of electrical excitation, Röntgen, and he alone, recognized, identified and reproduced the phenomenon with full awareness and command.

For the record, an interesting predecessor with proper documentation and sophisticated awareness of what had happened, and what failed to happen, was the instance of a report on 14 February 1896 in *Science* of New York by A. W. Goodspeed of the University of Pennsylvania in Philadelphia. He and an associate, after

photographing electric sparks and brush discharges as early as 22 February 1890, found their experimental table had held scattered photographic plate holders along with other laboratory equipment. Goodspeed had been experimenting with Crookes tubes and had subsequently, on developing the plates, observed that one contained two dark round discs as well as the usual tracings of the electric sparks upon the negatives. This curious shadowgraph could not be explained and the plate found its way to the shelf intended for future reexamination. There it lay for six years until the announcement by Röntgen. This prompted reexamination and a repetition of the experiment with confirming results. The story of the two experiments, made six years apart, was related by Goodspeed at a lecture on Röntgen rays at his university on 22 February 1896. His lecture was concluded by the statement, "We can claim no merit for the discovery, for no discovery was made. All we ask is that you remember, gentlemen, that six years ago, day for day, the first picture in the world by cathodic rays was taken in the Physical Laboratory of the University of Pennsylvania."*

It was also known that in his work with the Crookes tube in 1879 Sir William had fashioned a cathode ray tube in which the anode was a platinum leaf and the cathode of concave form. Crookes observed that photographic plates lying near his experimental tubes were frequently fogged. Some of these plates he returned to the manufacturer complaining of their spoiled condition. At least one other Englishman, H. Jackson, and two German physicists, Hittorf and Goldstein, as well as Lenard, had observed, before the Röntgen announcement was made, fluorescent glow in materials that were located near Crookes tubes. None of his predecessors had, however, properly recognized or identified the nature of the fluorescence or realized its

source, as Röntgen did. One of the earliest investigators of X-rays, Prof. Max Levy of Berlin, reminisced later, "I have no doubt that X-rays were seen in laboratories even before Röntgen's time, but they were not recognized as such by the investigators. The credit due to Röntgen is not decreased but is considerably increased by this fact because his genius discovered the significance of a thing which others had seen but did not recognize."*

A more dogged contender for the credit given Röntgen was Lenard, who never became reconciled to the fact that he had missed one of the greatest discoveries in all history by having failed to notice what Röntgen did. During the Nazi-oriented days of the mid-1930s, efforts were especially made to shift the credit for the X-ray discovery from Röntgen to Lenard, but to the more objective analysts it was evident that (1) Lenard was so involved in cathode ray behavior that he had missed noting what lay beyond the tube range, (2) the pentadezylparatolylketone screen he employed to explore the field was too weak to show what Röntgen's barium crystals showed, and (3) where Lenard surrounded his tube with a zinc box and thereby smothered the penetrating rays, Röntgen used a black cardboard cover, therewith least inhibiting the rays that caused the nearby screen to glow. Röntgen wrote specifically of his use of an all-glass Hittorf tube in his first communication, unlike Lenard's aluminum capped one. He generously gave Lenard what credit was due him for his earlier cathode ray investigation."**

*GLASSER, page 388.

**The vain and secretive nature of Lenard contrasted sharply with the modest and generous personality of Röntgen. Lenard became an ardent Nazi and, tho not of German origin, fostered "German physics". He lived to witness the collapse of his racist doctrines. See BARR, E. S., *American Journal of Physics*, May 1962, page 360, and GLASSER, Otto, *Radiology*, August 1936, page 139, and his "The Human Side of Science" in *Cleveland Clinic Quarterly*, July, 1953.

*GLASSER, page 223.

The electromagnetic spectrum

The electromagnetic manifestation we call light vibrates at different frequencies to produce the various colors of the spectrum visible to our eyes. In the range of colors and the corresponding range of vibrations, one end of the spectrum is that of red light, having a frequency of vibration of 400 trillion per second, and a wave length of 7×10^{-5} cm. As the frequency increases to approximately double that of red light, violet light is approached. Borrowing a term from acoustics, it can be said that the range of frequency of the visible spectrum covers one octave. Visible light rays occupy only one octave on a scale of more than 70 octaves of electromagnetic waves. From the long Hertzian waves used in radio that occupy 28 octaves we move thru the shorter infra-red rays (9 octaves), then into the visible rays and thru ultra-violet rays (5 octaves) into the 14 octaves of X-rays. These have a wave length of about 5×10^{-9} cm. and are followed by the even shorter wave lengths of radioactive substances and cosmic rays. Some of the above ranges overlap. X-rays have a wave length about 1/3000th that of visible rays.

Beyond the visible range, light invisible to our eyes may still be recorded on photographic plates; whereas red light has no effect on the ordinary photographic plate, light waves beyond our visible range, those in the ultra-violet region, do affect a photographic plate. Further increasing the frequency of vibrations brings the scale into the range of X-rays, then into the range of radioactive emanations or gamma rays, which can be plotted for about four octaves. Cosmic rays, having very short wave lengths (in the order of 1/500 millionth cm.) are therefore very penetrating. They are 100 times as penetrating as X-rays and can pass thru 25 feet of lead.

The first important improvement on the original Röntgen apparatus was a device to permit direct observation of an object, such as a hand, rather than an image on a photographic plate.



E. P. Thompson, Röntgen Rays, New York, 1896

An Early Fluoroscope

A quick way to examine X-ray emanation was to place a treated screen in front of a vacuum tube, using the hand to test the effectiveness of the ray. This very early form was later improved in shape and in the quality of the screen.

This was first described by the physicist E. Salvioni of Perugia, Italy, in February 1896. By placing a hand before a screen treated with platinocyanide and shielding out extraneous light from the eyes, the bone structure of the hand could be examined even as it moved. A further improvement was the recommendation of H. Jackson of London to treat the screen with the salt platinocyanide of potassium. This device, with its several subsequent improvements, became known as the "fluoroscope".

Thomas Edison turned to the problem of X-ray detection and observation and in his usual empirical procedure began experiments two days after the news had reached America to confirm Röntgen's discovery. In four days he had re-

peated the basic experiments and faced a battery of 20 newspaper men who had come to the laboratories to be briefed on the new marvels. Twelve reporters of the group remained there for two weeks. Edison concentrated on the problem of the fluorescent salts, convinced that there were more effective crystals to indicate the X-ray presence. He assigned four men to try many combinations of chemicals. Of the 8000 compounds which they tried, they selected several hundred which fluoresced under X-rays. Of these the most effective was calcium tungstate. This substance was then shaped into screens. In November 1896 Edison published a list of 72 substances which emitted fluorescent light when energized by X-rays. He also improved the shape of the fluoroscope. So many new designs and improvements were introduced into X-ray tube fabrication that, when Edison faced the choice of a preferred design in mid-1896, he chose from among 180 different variations of tubes.

The New York area was treated to a dramatic demonstration of X-rays in May 1896 when Edison arranged a demonstration in conjunction with the annual display of the National Electrical Exhibition. Preparations were made for allowing a substantial number of people to examine their hands with a portable fluoroscope. Many more people than were expected turned out for the demonstration and Edison's assistants had to cope with shock, incredulity and mirth as the crowd moved thru chambers darkened and hung with black cloths to improve their vision sensitivity. The visitors were guided thru heavy iron railings, signs along the way instructing them to slip a key or coin into a gloved hand so as better to see the bones of their hand and the objects in the glove.

Among the assistants at the apparatus was Mr. Clarence M. Dally who was in charge of the induction coil. The lengthy exposure to the virulent rays resulted in severe burns and finally caused his death in 1904. He thus was one of the earlier martyrs in a long chain of victims of

overexposure to the rays that were found to destroy as well as to serve usefully. As a result of the injuries to Dally, Edison discontinued experimenting with X-rays.

Application to medicine

The Edison laboratory was again besieged by reporters who learned that experiments had been undertaken to determine if blind eyes could be made to see simple shadows cast on their retinas by X-rays. The excitement, however promising, did not last long after Edison issued a curt negative statement in November 1896. Others in Germany, France and Italy also tried to register X-ray on eyes from which the lenses had been removed or which had suffered some other form of disturbance. Nothing of value resulted.

Many of the early users of the fluoroscope used one hand to hold the screen and held the other hand between it and the tube to gauge the strength of the X-ray emanation. The long time required for the eyes to adjust to the subdued light became a hazard to the hand and this all too often led to the disastrous chain of burns, lesions, amputations and ultimate death. Discussing only the American martyrs to X-rays during the first 40 years of their use, one biographer listed 26 men and one woman (army-technician Elizabeth F. Ascheim of San Francisco), sacrificed to the young science of roentgenology. As one among them wrote, "From my experience, and personal communications from patients, I believe that the agony of inflamed X-ray lesions is almost unequaled by any other disease."*

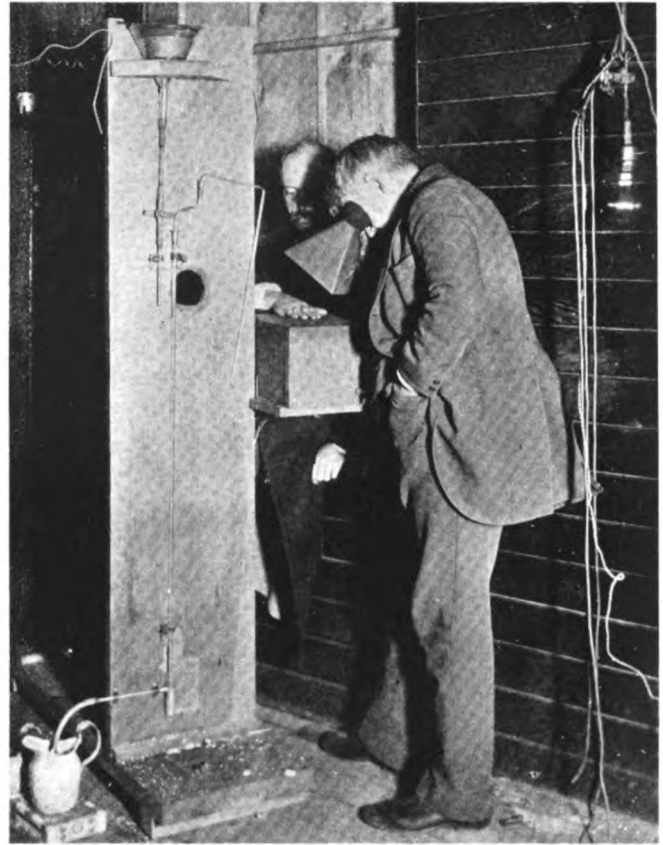
In the practical application of the new rays, it was the surgeons who found their diagnostic properties to be of immediate help. Röntgen himself had sent a print showing a fractured

*BROWN, Percy, M.D., *American Martyrs to Science through the Roentgen Rays*, Springfield, Ill. 1936, page vii.

forearm to the editor of the *British Medical Journal* on 15 February 1896. The value and importance of such an aid stirred the imagination of the physician and surgeon. A month earlier an X-ray exposure had been made in Frankfurt of the hand of a laboratory assistant who had once been injured by the explosion of a glass flask. A piece of glass had embedded itself in the hand and had remained there for a number of years much to the discomfort of the patient. This, because of its lead content, now appeared in the X-ray plate and its removal was simplified. This was followed by photographs of a needle in a girl's hand and another of a set of teeth, the latter made by exposing a small film wrapped in black paper and placed in the mouth of the patient. The skeletal structure of frogs and other animals and the secrets of wrapped mummies were exposed by X-ray analysis.

As researchers extended their investigations by refinements in clinical and photographic techniques, diagnostic help in cases of malignant tumors, arthritis and calcium deposits increased. Other practitioners injected opaque salt liquors into the viscera of animals to observe their shape and extension. The next step was to introduce air and chemical solutions to outline the living organs. It was then proposed that solution of the halogen compounds (bromide, chlorine, fluorine and iodine) would absorb X-rays and thereby show stomach and intestinal outline and function. W. B. Cannon of Harvard used a fluorescent screen in the autumn of 1896 to demonstrate the passage of spherical pearl buttons down the esophagus of a dog. He also watched the passage of gelatin capsules filled with a bismuth compound moving thru the stomach of a frog. The explosive urgency and many channels of research laid open to the physician, physicist, electrician and photographer cross-fertilized each other's practices; with comparatively simple equipment each moved into the other's field, with general beneficent results.

Progress in the application of Röntgen-ray

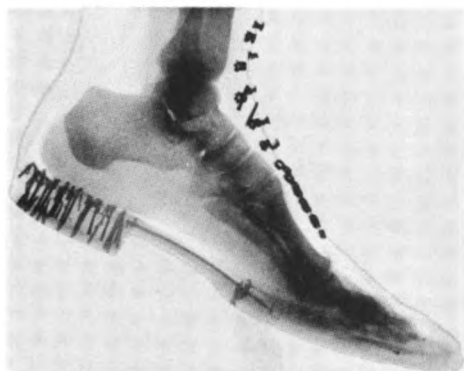


E. P. Thompson, Röntgen Rays, New York, 1896

Edison examines a hand thru a fluoroscope

Edison began a series of X-ray experiments immediately on learning of Röntgen's discovery. He tested hundreds of luminescent substances before choosing the most effective one. His assistant, Clarence Dally, holds his hand over a box-enclosed tube; Edison looks thru a fluoroscope of his design. The main apparatus, left, is a Sprengel vacuum pump.

technology to medical diagnosis proceeded more rapidly in America than elsewhere. An outstanding example of the medical possibilities of the ray was demonstrated immediately after the first announcement in New York in January 1896. This prompted Prof. Michael I. Pupin of Columbia University to release an X-ray picture which he had taken of the hand of a New York attorney, Mr. Prescott Hall Butler, in whose hand 40



Williams, Notes on X-rays in Medicine, Boston, April 1896

An early American X-ray

Considerable pride accompanied the publication of this radiograph taken in April 1896 by a Boston physician of his own foot. The exposure was 20 minutes.

shotgun pellets had lodged during an accidental discharge while on a hunting visit to England. The task of removal of the shot was immensely simplified for the surgeon.

Pupin had placed a fluorescent screen on the photographic plate and the hand was then placed over it; the exposure was thus reduced to only a few seconds. This was the first surgical operation performed from an X-ray plate and reflected the improvement of Pupin's arrangement; in addition to the intensifying screen, he used a Holtz electrostatic machine instead of an induction coil. Pupin recalled that "no other discovery within my lifetime had ever aroused the interest of the world as did the discovery of X-rays. Every physicist dropped his own research problems and rushed headlong into the research of the X-rays."*

*PUPIN, M.I., *From Immigrant to Inventor*, New York, 1923, page 306. Altho Pupin kept no records of his earliest X-ray experiments and claimed to have received reports from a German physicist before any published reports reached him, the probability is that his experiments were made in the first days of February 1896, which still places them among the first made in America. There are half a dozen claimants as the first to have made X-ray photographs in America.

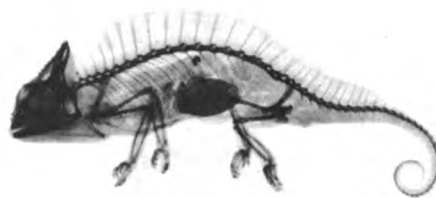
At hospitals and universities such as Harvard, Dartmouth, Cleveland and Pennsylvania, fractures and deformities became the ready subject of X-ray investigation. Dr. E. B. Frost of Dartmouth submitted a paper on his experiments with X-rays dated 4 February 1896, to the editors of *Science*. This, added to communications from Pupin of Columbia and Goodspeed of Pennsylvania, both dated 8 February, were published in the 14 February issue which also contained a translation of Röntgen's announcement. These were the earliest printed references to X-rays in America. Dr. Frost had photographed the broken arm of a young man in the physics laboratory at Dartmouth during the first week of February 1896. The story of the event and the picture of the lad's broken arm appeared shortly thereafter in *Harper's Weekly*. (See *frontispiece*).

More difficult problems, like photographing a thick section of the human body, were slowly solved with improvements in equipment and techniques. Soon the internal organs of soft tissue in the thorax and pelvis became discernible. The more ingenious practitioners acquired X-ray cabinets and their clinics and laboratories prospered. Hospitals soon considered an X-ray laboratory to be an essential part of their operations.

Wealthy individuals, foundations and governments made grants for X-ray research and new inventions. The noble and famous submitted to X-ray photography for various reasons. Li Hung-Chang, prime minister of China on a visit to Berlin, had his head X-rayed to show the location of a would-be assassin's bullet which had lodged in the soft tissues of the head. Prof. Elihu Thomson, electrical pioneer, X-ray inventor and a founder of the General Electric Company, had an X-ray made of a fractured leg. This helped in its setting, with a perfect mend. Emperor Wilhelm II of Germany had his withered left arm photographed in the hope of having some activity given to it.

While the therapeutic possibilities of X-rays were not yet realized, the malignancies that followed long exposure took their toll among the pioneers. There had been no indication that any special precautions should be taken against exposure to X-ray emanations. Röntgen's fortunate practice was to work in a zinc cabinet with a lead plate on the side. This left the tube outside the lead-plated wall which had an aluminum lens set into it to permit penetration of the rays into the chamber. This afforded Röntgen considerable protection, altho this accidental precaution was taken not for reasons of preventing exposure but rather to filter out stray emanations. Others intuitively took precautions against such powerful penetrating rays. By 1899 E. W. Caldwell of New York had developed a liquid interrupter in the induction coil circuit that enabled him to obtain clear radiographs with very short exposures, some in the order of a 1/5000th second.

Because the intensity of radiation was comparatively low, long exposures were often required, many lasting from 15 minutes to over an hour. In mid-1896 more reports began to be published of skin burns resembling strong sunburn and loss of hair at places exposed to X-rays. By October of that first year of X-ray practice, reports reached the press on the serious burns that followed long exposure to the new rays. Elihu Thomson decided to expose the little finger of his left hand by placing it only one and one half inches from an X-ray tube for one half hour. Pain later began to be felt and in a week the finger reddened, swelled, and became stiff and painful. Even seventeen days after the exposure, his finger was still sore. However, he could with certainty eliminate electrostatic discharge as the cause of the swelling, contrary to what some had claimed. He cautioned experimenters to avoid long X-ray exposure at close proximity to the tube. The intractable burn on Thomson's little finger resulted in a scar which remained for the rest of his life and which he



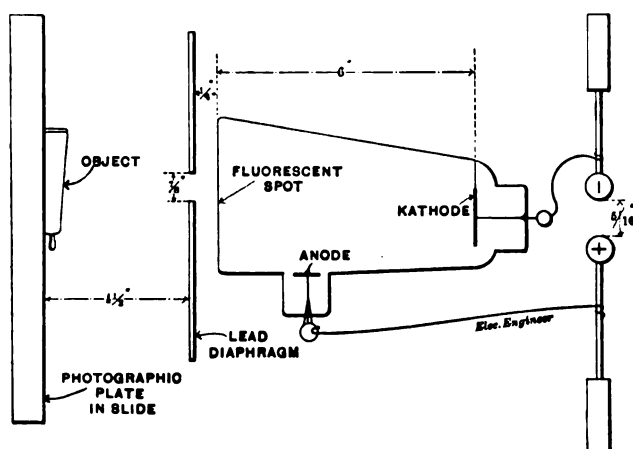
Eder und Valenta, Photographie, 1896

African chameleon

In Vienna in February 1896 there appeared a large portfolio of 15 superb reproductions of radiographs of hands, feet, animals and objects, in negative and positive prints. All indicated advanced laboratory technique.

used as a warning to those who would be careless with X-rays.

No less an authority than Sir Joseph Lister spoke of the serious irritations that might be caused by the penetrating rays, especially on the internal organs. He also anticipated possible healthful stimulation by the rays. The application of X-rays in the constant war on bacteria was immediately considered in America and in Germany. Yet the early experiments showed little if any bactericidal effect on the more virulent bacteria. However, in June 1896, two French physicians, Lortet and Genoud, reported positive germicidal results with X-rays. They had injected the same area of eight rabbits with tubercle bacilli and then treated three to daily doses of X-rays over a period of eight weeks. Whereas the untreated rabbits developed abscesses, those that were irradiated showed good health. While cures for such diseases as tuberculosis were claimed by impatient practitioners, the therapeutic value of Röntgen's rays was far from proved, probably because of the low intensity of the radiant energy generated at that time.



E. P. Thompson, Röntgen Rays, New York, 1896

Improving the X-ray photograph

Altho Röntgen used an induction coil to generate the high voltages needed to excite a cathode ray, others found that a Wimshurst or Holtz machine created a clearer ray. The above diagram, by E. W. Rice of Schenectady, had the additional feature of a lead shield with a hole to provide a directed beam. It was first published in April 1896.

The enormous scientific expansion and crossing of disciplines was clearly envisaged by Ludwig Boltzmann as early as 15 January 1896 when he said, "If we remember to what discoveries the investigation of very insignificant natural phenomena have lead us, as, for example, the attraction of small bodies by rubbed amber, of iron by the lodestone, the convulsive twitches of a frog's leg due to electric discharges, the influence of the electric current on the magnetic needle, electro-magnetic induction etc., we can imagine the possibilities of application of an agent which has given rise to such surprising results within a few weeks after its discovery."*

The expanding use of X-ray equipment by hospitals and private medical laboratories forced scientific instrument makers, glass blowers and electrical equipment manufacturers to expand

*GLASSER, page 249.

their facilities and work late into the night. Many had to learn the refinements and complexities of X-ray apparatus and photographic screens and plates. The fabricators of induction coils and tubes were quite overwhelmed by the sudden demand for such laboratory products. One German manufacturer, Robert Goetze of Leipzig, complained of the sudden demand for several hundred vacuum tubes. Of these, 70 orders were received by him in a single day when he already had enough work to tax his facilities for a full year ahead.

Improved techniques

The Crookes tube which Röntgen used in his earliest work of discovery was pear-shaped with the anode at the maximum bulge and the cathode in the narrow end of the tube axis. Because the focal spot of the cathode ray on the glass wall was not steady but diffuse, the exposure time was necessarily long. Attempts to clarify and sharpen the resulting picture were made by the addition of a lead sheet in front of the tube, the sheet or diaphragm having a small hole so as to form a narrow beam.

The determination of the source of X-ray emission was made in an impressive series of 40 experiments by two Russians, Prince Galitzin* and A. de Karnojitzky, in a memoir published in St. Petersburg in March 1896. They prepared a board studded in a simple pattern with nails, placed a photographic plate beneath the board and exposed the assembly to the rays from 13 different radiation tubes. A study of the nail shadows showed clearly that most of the X-rays emanated from the cathode. In 12 exposures, secondary centers, and even tertiary centers, were noted.

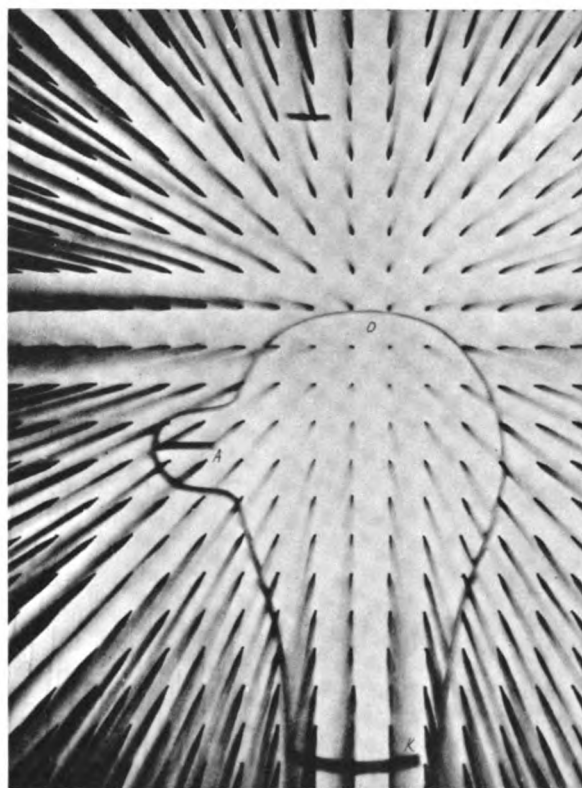
*GALITZIN, B., und KARNOJITZKY, A.V., *Über die Ausgangspunkte und Polarisation der X-Strahlen.*, St. Petersburg, 6 March 1896. An earlier Prince Dmitri A. Gallitzin (1738-1803) had lectured and published many memoirs on the properties of static electricity in the 1780s.

Limited by the understanding of physics of the time, efforts were made to define the exact nature and behavior of X-rays, and to determine whether the new variant was wave, particle, vortex, ether, a combination of these, or an entirely new element in nature; there was no shortage of speculation. One firm property of X-rays was shown in Paris in February 1896 when it was demonstrated that air and other gases, as well as such insulating materials as paraffin, mica and sulfur, could be ionized by X-rays and made electrically conductive. This was a great boon to X-ray investigation because, with the use of a simple electroscope, the presence of X-rays could be established and their intensity readily measured.* The process of ionization (and loss of an electric charge) was not hindered by a zinc plate a quarter inch thick through which the X-rays penetrated. This method of identifying and measuring the intensity of X-rays was much simpler and quicker than using photographic plates. A new microcosm was revealed by the placing of the new ray at the command of the physicist. The very nature of matter, of energy, ether, waves and particles—the whole physical world of man now came under his intense scrutiny.

The third communication

The third and final communication by Röntgen bore the title "Further Observations on the property of the X-ray" and appeared in May 1897. It was submitted to the Prussian Academy of Sciences in Berlin rather than to the Physical-Medical Society of Würzburg to which the first two communications had been submitted. All three papers were subsequently reprinted with-

*The unit for measuring the intensity of X-ray radiation was established in Stockholm in 1928 as the "röntgen" or *r*. It is that radiation that produces one electrostatic unit in one cubic cm. of dry air at zero degrees C. and at 760 mm. of mercury. This is the equivalent of producing two billion each of positive and negative ions.



Худож. Фототип. А. И. Вильногга. С.-Петербургъ, Мѣщ. 19.

Galitzin and Karnojitzky, X-Strahlen, 1896

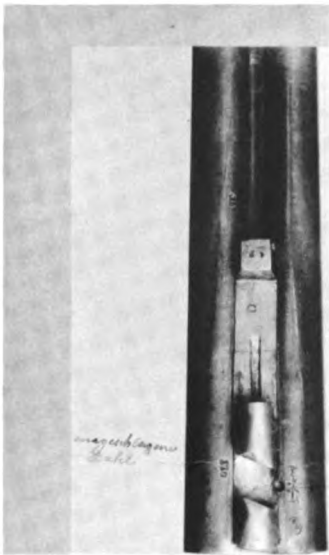
Center of X-ray emanation

In a report to the Imperial Academy of Science in St. Petersburg in March 1896, two Russian scientists showed the source of X-rays O in tubes of various shapes. A is the anode; K, bottom, the cathode.

out alteration or comment in January 1898 in the much read *Annalen der Physik und Chemie*.

Beginning with a discussion of the determination of X-ray diffraction, especially by air, Röntgen concerned himself with the variances that affected the intensity of radiation and the means of measuring it. Eight variables were listed that produced differing intensities of X-ray brightness on a fluorescent screen. In striving for more intense rays, Röntgen concluded that if the platinum wafer were set so as to reflect the cathode rays at an angle of 55° , maximum emission would thereby be attained. The angle between the platinum wafer and the absorbing

THE NEW RAYS OF



Courtesy, Prof. A. R. von Hippel of M.I.T.

Röntgen X-rays his favorite gun

Using X-rays from a "hard" tube, Röntgen took these remarkable radiographs of the breech of his favorite double-barrel gun. These he annotated and sent to his friend Arthur von Hippel thru the courtesy of whose grandson they are here reproduced. The left photo shows the stamped bore and indent markings; the right radiograph shows the shells with lead pellets and shot, the primer, wadding and powder in place.

screen or photographic plate was not to exceed 80° . He conjectured that the platinum plate absorbed the cathode rays more than the X-rays which they produced.

By photometric means, Röntgen showed that in using the same power supply and apparatus and changing only tubes, he was able to obtain five times as much intensity of ray as from another tube of the same general construction. He thereupon classified the more penetrating tubes as "hard" and those of weaker strength as "soft". He chose from such a variety of emission tubes those which best suited the object to be photographed. If, for instance, one was more

interested in the bone structure of a hand, a harder tube was desired; for the fleshy parts, a soft tube was preferred. He observed the tendency of tubes to become harder with continued use, thereby indicating a continued self-exhaustion of the remaining gas particles. With such a hard tube, Röntgen proudly showed an X-ray photograph of a double-barreled hunting rifle with cartridges in place. Not only the internal parts of the cartridges but also the construction and embossing details of the barrels were visible.

Before ending his final report, Röntgen listed a number of inconclusive areas of investigation; he could still not influence X-ray deflection by

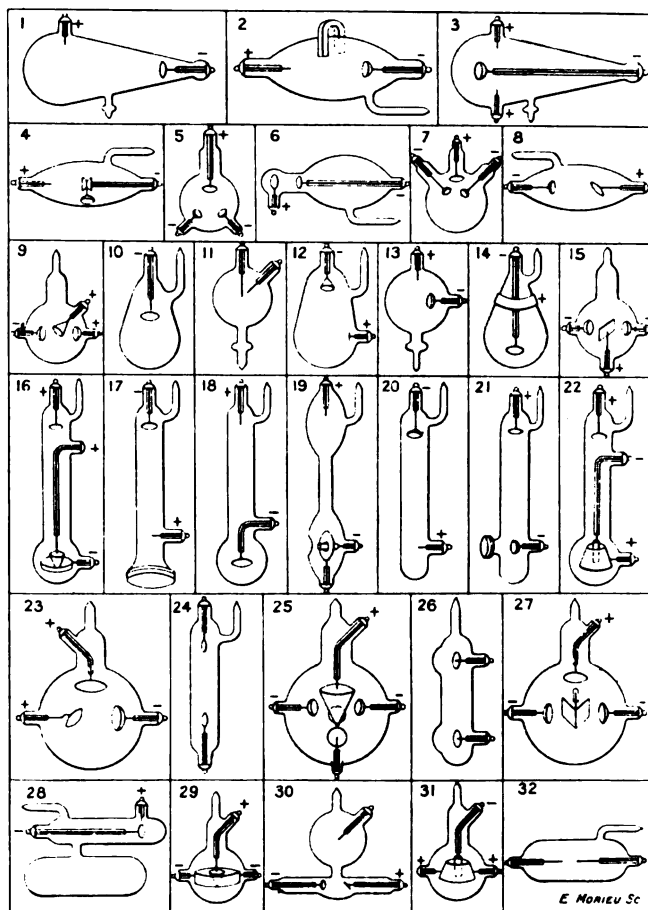
magnetic means. The rays, in passing thru calcite, quartz, beryl or other crystals, showed no change in direction; therefore, no refraction. There was very limited observation of the rays by the retina of the eye, even if others claimed such visibility. There was, finally, still nothing to report on X-ray diffraction.

Röntgen's last published paper appeared in 1921, occupied 195 pages in the *Annalen der Physik und Chemie*, and was concerned with photoconductivity in crystals. Its length and avoidance of reference to all gas-discharge phenomena and X-rays prompts one to conclude that this paper must reflect a lifetime interest by Röntgen in the physics of solids, especially crystals.

Of the 17 numbered items in Röntgen's first communication, it was item three that led to the next (and for 40 years most important) step forward in physics. In this statement, Röntgen noted that the transparency of different substances to the new rays was related to their densities. Having come to this general conclusion, Röntgen stated that on comparing the transparency of glass, aluminum, calcspar and quartz of about equal thickness, it appeared that calcspar showed less transparency than the other three materials. J. J. Thomson, assisted by Ernest Rutherford and working in the Cavendish Laboratory at Cambridge, followed this lead in a series of penetrating experiments.

In a joint paper presented in November 1896 and published in the *Philosophical Magazine* under the title "On the Passage of Electricity through Gases Exposed to Röntgen Rays"*, it was stated that a normally insulating gas can be made conductive by the application of X-rays. This provided the physicist with a new means of studying the properties of gases and of matter itself. It was also shown that a gas retained its conductive properties for a short time after the passage of the rays thru it. The passage of an

*Reprinted in Alembic Club Reprint No. 22.



1, 2. Crookes; 3. Ségué; 4. Wood; 5. Ségué; 6. Chabaud and Hurmuzescu; 7. Ségué; 8. "Focus"; 9. Ségué; 10. d'Arsonval; 11. Ségué; 12. Puluj; 13. Ségué; 14. d'Arsonval; 15. Le Roux; 16, 17, 18. Ségué; 19. Ruzf; 20. Crookes; 21, 22, 23. Ségué; 24. Röntgen; 25. Brunet-Ségué; 26, 27. Le Roux; 28. Colardeau; 29. Ségué; 30. Colardeau; 31. Ségué; 32. Röntgen. (*Nature*, January 28th, 1897, after *La Nature*.)

From Colwell, History of Electrotherapy, London, 1922

Vacuum tubes used to produce Cathode and X-rays, 1896

Air-exhausted tubes had been used experimentally for about 45 years to produce luminescent phenomena. Such variables as gas density and kind, applied voltage and frequency, externally applied magnetic and electric fields, or combinations of these, fostered the variety shown above at the time of Röntgen's activity.

electric current thru the treated gas destroyed its conductive properties, similar to an electrolyte.

During the next year, in his paper on "Cathode Rays", J. J. Thomson gave the first account of his discovery of the electron. Weigh-

ing the ether wave theory against the electrified particle theory, he presented experiments to show that "something" charged with negative electricity was shot off from the cathode and that it could be deflected by a magnet. He also deflected cathode rays by electrostatic forces and confirmed that the rays behaved as if they were negatively electrified. He therefore concluded that the ray could be nothing else than negative electricity carried by particles of matter. He then asked, "What are these particles? are they atoms or molecules, or matter in a still finer state of subdivision?"*

Thomson concluded that in the discharge tube the cathode rays were formed by a stream of electrons repelled by the negatively charged cathode and were hurled against the target, which might be the glass of the tube or a deflecting metal plate. Electrons torn from orbits close to the nucleus possessed great kinetic energy and, on leaving the atom, created a state of electrification or ionization of the atom structure that generated X-rays which travelled at less than the speed of light. Thomson had published results of X-ray experiments in 1896 in which he disclosed that when a gas was treated with these rays it became ionized and conductive. However, he found it gradually lost this property. Rowland, discussing the advances of X-ray investigation during its first year, stated "that a certain amount of gas will conduct a certain amount of electricity, and then it stops conducting . . . It is one of the great advances we made since Röntgen's discovery. Röntgen knew nearly all we know about these rays."**

The relationship between fluorescence and the generation of X-rays was explored by Stokes***, who observed that a metallic target

generated X-rays even without fluorescence and that when a spot on the glass wall of a Crookes tube had received concentrated exposure to cathode rays and thus became comparatively dull, it did not affect the emission of the X-rays.

As predicted and named by G. Johnstone Stoney of Dublin in 1891, the "electron" represented the primary unit or ultimate quantum of negative electricity, carried by the hydrogen atom when water was decomposed. In 1897 J. J. Thomson showed that its measurable value, represented as a ratio of its charge to unit mass, e/m , was the same irrespective of the kind of glass from which the vacuum tube was made, the residue of gas it contained or the kind of metal electrodes used within it. For hydrogen, the electron mass was determined to be $1/1850$ th that of the atom. A further conclusion was that electrons in a vacuum moved at speeds approaching that of light. The chemists' firm atom had become decomposed into a new, open, sub-atomic structure. The disintegration of the classic atom of Dalton, with its already minute dimension of a 10^{-8} cm. diameter, was now dismembered into electrons of the order of 3×10^{-13} cm. and even smaller protons of about 6×10^{-16} cm.*

Further X-ray discoveries

A few weeks after the discovery of X-rays was announced, Antoine H. Becquerel turned them on phosphorescent substances, hoping to associate the rays with the glow on the luminescent screen. Hunting for similar emission properties, he found that when uranium salt crystals were first made phosphorescent by exposure to sunlight and then placed over wrapped photographic plates, an image was produced on the plates. However even without previous exposure to light, the image was again found to register. The next step was to place an aluminum medalion on a fresh photographic plate and cover it

*Quoted by MAGIE, William F., *A Source Book in Physics*, New York 1935, page 589.

**ROWLAND, Henry A., "The Röntgen Ray, and its Relation to Physics," *Transactions, A.I.E.E.*, New York, 16 Dec. 1896, page 406.

***STOKES, Sir George G., "On the Nature of the Röntgen Rays", in *Manchester Memoirs*, No. 15, 1897, page 20.

*KAYE, G.W.C., *Roentgenology*, London, 1928, page 66.

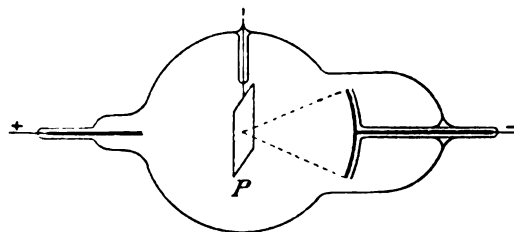
with some uranium ore. After a long exposure, the developed plate showed the definite image of the medallion. Other uranium-containing ores gave the same results.

The search for the active ingredient led to the ore pitchblende, a mineral derived from mines in north Bohemia made famous by Agricola in the mid-1500s. The search for the specific source of the more powerful radioactive elements was taken up by Marie S. Curie and her husband Pierre, working under most difficult laboratory conditions in Paris. The results of their work led to the discovery of radium and polonium and the award of the Nobel Prize to Becquerel and the Curies in 1903. The radium of the Curies proved to be a million times more radioactive than uranium. Radium waves were found to be even shorter than X-rays, in the order of $1/200,000$ th cm., and therefore were more penetrating than Röntgen's rays.

It was Becquerel who, after carrying a minute quantity of radium bromide in his vest pocket (for safekeeping) for about six hours, discovered a week later that a redness which had developed on the skin under the pocket changed to an ulceration which was not relieved for more than a month. This led to the investigation of the therapeutic value of radiation, paralleling similar investigation of X-rays, generally with positive results.

Another threshold was crossed in 1905 when Einstein attempted to unite the new phenomena of the past decade by applying his concept of relativity, and stated that the mass of a body should change with its speed. He held that matter could be converted into energy, and energy into matter. He then expressed this relationship in the most famous formula ever written: $E=mc^2$, where energy E equalled the mass times the square of the velocity of light.

Other scientific discoveries followed the conclusion by J. J. Thomson that cathode rays consisted of a stream of particles of very low mass moving at very great velocities (nearly that of



*Hittorfröhre,
mit der Röntgen seine Strahlen entdeckte
(zu S. 622).*

From Zehnder, Erinnerungen an Röntgen, Basel, 1933

Röntgen's X-ray vacuum tube

The reticent Röntgen did not steep his reports in details; it remained for his assistant and friend, L. Zehnder, to identify the type of tube that was used in the discovery of X-rays.

light). He was the first to succeed in deflecting the minute particles by an electric as well as by a magnetic field; he was the first to postulate that the electron was a constituent of all atoms and to design experimental methods of determining the number of such electrons. Dr. Charles E. Barkla of England succeeded in partially polarizing X-rays in 1904. There followed the application by young H. G. J. Moseley who, by making X-ray spectra of many elements, showed the uniform variation from one element to the next by the shift in frequency of line. Then Chadwick followed with the discovery of the neutron. This helped explain the existence of isotopes, variants of ordinary elements having the same nuclear charge but with different nuclear masses. Various models were then attempted to illustrate the complex arrangements of the new atomic architecture. X-ray microscopes were developed and the very form of matter and its atomic patterns was investigated. The analysis of crystal structure by X-ray diffraction was begun by Max von Laue in 1912. When in that year Röntgen examined the results of experiments to demonstrate interference of X-rays in crystals, he beamed with delight at the confirmation of what had seemed

to him probable but had been so difficult to accomplish.*

Röntgen had speculated that his new rays might be some kind of light rays of the ultra-violet type and that the extreme shortness of the waves explained the absence of reflection, refraction, diffraction and polarization. Von Laue conjectured that man-made gratings were too coarse to be used for such short wave lengths and therefore recommended the natural gratings of crystalline materials. With these, he and others established more of the true nature of X-rays and, at the same time, used these rays to investigate crystal structures. This was the field intensively cultivated by the Braggs, father and son, who opened X-ray spectroscopy to the physicist and the chemist.

Sir William H. Bragg followed von Laue's discovery of X-ray diffraction in 1912 by experiments intended to show that these rays were actually particles. However, thru his own experiments, he arrived at the conclusion that they were really waves. This dichotomy brought from him the famous quip, made in 1928, to the effect that the corpuscular theory applied on Monday, Wednesday and Friday, and the wave theory on Tuesday, Thursday and Saturday.

At the suggestion of C. T. R. Wilson, Sir Lawrence Bragg reflected X-rays from a cleavage face of mica in 1912. To improve further the technique of measuring X-ray emanations, his father, Sir William Bragg, devised the X-ray spectrometer for measuring the character of layers of atoms parallel to the reflecting surface by determining the strength of the reflected beam in an ionization chamber. This proved to be a

revolutionary device for analyzing the atomic structure of all crystalline systems. With this the Braggs measured the wave lengths of X-ray spectra from the elements platinum, osmium, iridium, palladium, rhodium, copper and nickel; the firm foundations of X-ray spectroscopy were set. Techniques were subsequently extended to analysis of the giant molecules of living substances and protein molecules composed of some 10,000 atoms. X-ray analysis has since been applied very effectively to the synthesis of completely organic compounds, to industrial salts and silicates, to the improvement of metals and alloys and the creation of new plastics and polymers. The seed planted by Röntgen continues to provide fruit from an ever-growing arbor.

By improved method, sharper instrumentation and wider exchange of results, physicists became so much more penetrating and confident that one of them, F. W. Aston of Cambridge, said, as far back as 1936, "Armed with such knowledge the nuclear chemists, I am convinced, will be able to synthesize elements just as ordinary chemists synthesize compounds, and it may be taken as certain that in some reactions sub-atomic energy will be liberated . . . There are those about us who say that such research should be stopped by law, alleging that man's destructive powers are already large enough . . . Personally I think there is no doubt that sub-atomic energy is available all around us, and that one day man will release and control its almost infinite power. We cannot prevent him from doing so and can only hope that he will not use it exclusively in blowing up his next door neighbour."*

*Mainly the work of von Laue, Friedrich and Knipping in Germany and W. H. Bragg and his son W. L. Bragg in England.

*In *Background to Modern Science*, Cambridge, 1938, page 113.

PROFESSOR RÖNTGEN

Sixty-seven years have passed since the keen eyes of Prof. Wilhelm Conrad Röntgen first observed a patch of glowing crystals, a phenomenon not readily understood by his trained mind. Since the recording of that epochal event we have moved into a realm of science undreamed of by the most optimistic and imaginative savants. The material world about us is now regarded with new understanding; the living world is engaged by forces and processes bearing the essence of freshness of the research laboratory.

A measure of the importance of new dis-

coveries in science has been the establishment of the Nobel Prize, beginning with the award to Röntgen. This year it has gone to three men who applied X-ray diffraction to the exquisitely complex and subtle mechanism that determines the factors of heredity in the living cell, undoubtedly the major assignment to science today.

Once again in the annals of science, applying the means of discovery to the urge to understand (research), there came the reward—new knowledge. The *use* of this knowledge pertains to yet another human attribute, one more difficult to attain—wisdom.



A Röntgen Museum was established at Lennep, the city of his birth, in 1923. It has since been expanded and has become a world center of roentgenology.

The widespread notice given to the Röntgen announcement (see footnote, page 22) prompted its immediate translation and publication in journals of science. Below is reproduced the translation in The Electrician of London.

THE ELECTRICIAN, JANUARY 24, 1896.

ON A NEW FORM OF RADIATION.*

BY PROF. WILHELM KONRAD RÖNTGEN.

1. If we pass the discharge from a large Ruhmkorff coil through a Hittorf or a sufficiently exhausted Lenard, Crookes, or similar apparatus, and cover the tube with a somewhat closely-fitting mantle of thin black cardboard, we observe in a completely-darkened room that a paper screen washed with barium-platino-cyanide lights up brilliantly and fluoresces equally well whether the treated side or the other be turned towards the discharge tube. Fluorescence is still observable 2 metres away from the apparatus. It is easy to convince oneself that the cause of the fluorescence is the discharge apparatus and nothing else.

2. The most striking feature of this phenomenon is that an influence (*Agent*) capable of exciting brilliant fluorescence is able to pass through the black cardboard cover, which transmits none of the ultra-violet rays of the sun or of the electric arc, and one immediately inquires whether other bodies possess this property. It is soon discovered that all bodies are transparent to this influence, but in very different degrees. A few examples will suffice. Paper is very transparent;† the fluorescent screen held behind a bound volume of 1,000 pages still lighted up brightly; the printer's ink offered no perceptible obstacle. Fluorescence was also noted behind two packs of cards; a few cards held between apparatus and screen made no perceptible difference. A single sheet of tinfoil is scarcely noticeable; only after several layers have been laid one the top of each other is a shadow clearly visible on the screen. Thick blocks of wood are also transparent; fir planks 2cm. to 8cm. thick are but very slightly opaque. A film of aluminium about 15mm. thick weakens the effect very considerably, though it does not entirely destroy the fluorescence. Several centimetres of vulcanised india-rubber let the rays through.‡ Glass plates of the same thickness behave in a different way, according as they contain lead (flint glass) or not; the former are much less transparent than the latter. If the hand is held between the discharge tube and the screen, the dark shadow of the bones is visible within the slightly dark shadow of the hand. Water, bisulphide of carbon, and various other liquids behave in this respect as if they were very transparent. I was not able to determine whether water was more transparent than air. Behind plates of copper, silver, lead, gold, platinum, fluorescence is still clearly visible, but only when the plates are

not too thick. Platinum 0.2mm. thick is transparent; silver and copper sheets may be decidedly thicker. Lead 1.5mm. thick is as good as opaque, and was on this account often made use of. A wooden rod of 20 x 20mm. cross-section, painted white, with lead paint on one side, behaves in a peculiar manner. When it is interposed between apparatus and screen it has almost no effect when the X-rays go through the rod parallel to the painted side, but it throws a dark shadow if the rays have to traverse the paint. Very similar to the metals themselves are their salts, whether solid or in solution.

3. These experimental results and others lead to the conclusion that the transparency of different substances of the same thickness is mainly conditioned by their density; no other property is in the least comparable with this.

The following experiments, however, show that density is not altogether alone in its influence. I experimented on the transparency of nearly the same thickness of glass, aluminium, calcspar and quartz. The density of these substances is nearly the same, and yet it was quite evident that the spar was decidedly less transparent than the other bodies, which were very much like each other in their behaviour. I have not observed calcspar fluoresce in a manner comparable with glass.

4. With increasing thickness all bodies become less transparent. In order to find a law connecting transparency with thickness, I made some photographic observations, the photographic plate being partly covered with an increasing number of sheets of tinfoil. Photometric measurements will be undertaken when I am in possession of a suitable photometer.

5. Sheets of platinum, lead, zinc and aluminium were rolled until they appeared to be of almost equal transparency. The following table gives the thicknesses in millimetres, the thicknesses relative to the platinum sheet, and the density:—

Thickness.	Relative thickness.	Density.
Pt. 0.018	1	21.5
Pb. 0.05	3	11.3
Zn. 0.10	6	7.1
Al. 3.5	200	2.6

It is to be observed in connection with these figures that although the product of the thickness into the density may be the same, it does not in any way follow that the transparency of the different metals is the same. The transparency increases at a greater rate than this product decreases.

6. The fluorescence of barium-platino-cyanide is not the only recognisable phenomenon due to X-rays. It may be observed, first of all, that other bodies fluoresce—for example, phosphorus, calcium compounds, uranium glass, ordinary glass, calcspar, rock salt, &c.

Of especial interest in many ways is the fact that photographic dry plates show themselves susceptible to X-rays. We are thus in a position to corroborate many phenomena in which mistakes are easy, and I have, whenever possible, controlled each important ocular observation on fluorescence by means of photography. Owing to the property possessed by the rays

* Preliminary Communication to the Würzburg Physico-Medical Society. Published by Messrs. Stahel, of Würzburg, who will shortly also issue an English edition.

† By the "transparency" of a body I denote the ratio of the brightness of a fluorescent screen held right behind the body in question to the brightness of the same screen under exactly the same conditions, but without the interposing body.

‡ For brevity's sake I should like to use the expression "rays," and to distinguish these from other rays I will call them "X-rays."

of passing almost without any absorption through thin sheets of wood, paper, or tinfoil, we can take the impressions on the photographic plate inside the camera or paper cover whilst in a well-lit room. In former days this property of the ray only showed itself in the necessity under which we lay of not keeping undeveloped plates, wrapped in the usual paper and board, for any length of time, in the vicinity of discharge tubes. It is still open to question whether the chemical effect on the silver salts of photographic plates is exercised directly by the X-rays. It is possible that this effect is due to the fluorescent light which, as mentioned above, may be generated on the glass plate or perhaps on the layer of gelatin. "Films" may be used just as well as glass plates.

I have not as yet experimentally proved that the X-rays are able to cause thermal effects, but we may very well take their existence as probable, since it is proved that the fluorescent phenomenon alters the properties of X-rays, and it is certain that all the incident X-rays do not leave the bodies as such.

The retina of the eye is not susceptible to these rays. An eye brought close up to the discharge apparatus perceives nothing, although, according to experiments made, the media contained in the eye are fairly transparent.

7. As soon as I had determined the transparency of different substances of various thicknesses I hastened to ascertain how the X-rays behaved when passed through a prism—whether they were refracted or no. Water and carbon disulphide in prisms of about 30deg. refractive angle showed neither with the fluorescing screen nor with the photographic plate any sign of refraction. For purposes of comparison the refraction of light rays was observed under the same conditions; the refracted images on the plate were respectively about 10mm. and 20mm. from the non-refracted one. With an aluminium and a vulcanised-rubber prism of 30deg. angle I have obtained images on photographic plates in which one may perhaps see refraction. But the matter is very uncertain, and even if refraction exist it is so small that the refractive index of the X-ray for the above materials can only be, at the highest, 1.05. Using the fluorescent screen, I was unable to discover any refraction at all in the case of the aluminium and the rubber prism.

Researches with prisms of denser metals have yielded up to now no certain results, on account of the small transparency and consequently lessened intensity of the transmitted ray.

In view of this state of things, and the importance of the question whether X-rays are refracted on passing from one medium to another, it is very satisfactory that this question can be attacked in another way than by means of prisms. Finely-powdered substances in sufficient thicknesses only allow a very little of the incident light to pass through, and that is dispersed by refraction and reflection. Now, powdered substances are quite as transparent to X-rays as are solid bodies of equal mass. Hence it is proved that refraction and regular reflection do not exist to a noticeable degree. The experiments were carried out with finely-powdered rock salt, with pulverulent electrolytic silver, and with the zinc powder much used in chemical work. In no case was any difference observed between the transparency of the powdered and solid substance, either when using the fluorescent screen or the photographic plate.

It follows from what has been said that the X-rays cannot be concentrated by lenses; a large vulcanised-rubber and glass lense were without influence. The shadow of a round rod is darker in the middle than at the edge; that of a tube filled with any substance more transparent than the material of the tube is lighter in the middle than at the edge.

8. The question of the reflection of the X-rays is settled in one's mind by the preceding paragraphs, and no appre-

ciable regular reflection of the rays from the substances experimented with need be looked for. Other investigations, which I will describe here, lead to the same result. Nevertheless, an observation must be mentioned which at first sight appears to contradict the above statement. I exposed a photographic plate to the X-rays, protected against light rays by black paper, the glass side being directed towards the discharge tube. The sensitive layer was nearly covered, star-fashion, with blanks of platinum, lead, zinc, and aluminium. On developing the negative it was clearly noticeable that the blackening under the platinum, lead, and especially under the zinc, was greater than in other places. The aluminium had exercised hardly any effect. It appeared, therefore, that the three above-mentioned metals had reflected the rays. Nevertheless, other causes for the greater blackening were thinkable, and in order to make sure I made a second experiment, and laid a piece of thin aluminium, which is opaque to ultra-violet rays though very transparent to X-rays, between the sensitive layers and the metal blanks. As again much the same result was found, a reflection of X-rays by the above-mentioned metals was demonstrated. But if we connect these facts with the observation that powders are quite as transparent as solid bodies, and that, moreover, bodies with rough surfaces are, in regard to the transmission of X-rays, as well as in the experiment just described, the same as polished bodies, one comes to the conclusion that regular reflection, as already stated, does not exist, but that the bodies behaved to the X-rays as muddy media do to light.

Again, as I could discover no refraction at the point of passage from one medium to another, it would seem as if the X-rays went through all substances at the same speed, and that in a medium which is everywhere, and in which the material particles are embedded; the particles obstructing the propagation of the X-rays in proportion to the density of the bodies.

9. Hence it may be that the arrangement of the particles in the bodies influence the transparency; that, for example, equal thicknesses of calcspar would exhibit different transparencies according as the rays were in the direction of the axis or at right angles to it. Researches with calcspar and quartz have yielded a negative result.

10. It is well known that Lenard, in his beautiful investigation on Hittorf cathode rays passed through thin aluminium foil, came to the conclusion that these rays were actions in the ether, and that they pass diffusively through all bodies. I have been able to say the same about my rays.

In his last work Lenard has determined the absorption coefficient of various bodies for cathode rays, and amongst other things for air atmospheric pressure at 4.1, 3.4, 3.1, at per centimetre, and found it connected with the exhaustion of the gas contained in the discharge apparatus. In order to estimate the discharge pressure by the spark-gap method, I used in my researches almost always the same exhaustion. I succeeded with a Weber photometer (I do not possess a better one) in comparing the intensity of the light of my fluorescing screen at distances of about 100mm. and 200mm. from the discharge apparatus, and found in the case of three tests agreeing well with one another that it varied very nearly inversely as the square of the distance of the screen from the discharge apparatus. Hence the air absorbs a very much smaller fraction of the X-rays than of the cathode rays. This result is also quite in agreement with the result previously mentioned, that the fluorescing light was still observable at a distance of 2 metres from the discharge apparatus.

Other bodies behave generally like air—that is to say, they are more transparent for X-rays than for cathode rays.

11. A further noteworthy difference in the behaviour of cathode rays and X-rays consists in the fact that, in spite of

many attempts, I have not succeeded, even with very strong magnetic fields, in deflecting X-rays by a magnet. The magnetic deflection has been up to now a characteristic mark of the cathode ray; it was, indeed, noticed by Hertz and Lenard that there were different kinds of cathode rays "distinguishable from one another by their phosphorescing powers, absorption and magnetic deflection," but a considerable deflection was nevertheless observed in all cases, and I do not think this characteristic will be given up without overwhelming evidence.

12. After experiments bearing specially on this question it is certain that the spot on the wall of the discharge apparatus which fluoresces most decidedly must be regarded as the principal point of the radiation of the X-rays in all directions. The X-rays thus start from the point at which, according to the researches of different investigators, the cathode rays impinge upon the wall of the glass tube. If one deflects the cathode rays within the apparatus by a magnet it is found that the X-rays are emitted from another spot—that is to say, from the new termination of the cathode stream.

On this account, also, the X-rays, which are not deflected, can not merely be unaltered reflected cathode rays passing through the glass wall. The greater density of the glass outside the discharge tube cannot, according to Lenard, be made responsible for the great difference in the "deflectability."

I therefore come to the conclusion that the X-rays are not identical with the cathode rays, but that they are generated by the cathode rays at the glass wall of the discharge apparatus.

13. This excitation does not only take place in glass, but also in aluminium, as I was able to ascertain with an apparatus closed by a sheet of aluminium 2mm. thick. Other substances will be studied later on.

14. The justification for giving the name of "rays" to the influence emanating from the wall of the discharge apparatus depends partly on the very regular shadows which they form when one interposes more or less transparent bodies between the apparatus and the fluorescing screen or photographic plate. Many such shadow-pictures, the formation of which possesses a special charm, have I observed some photographically. For example, I possess photographs of the shadow of the profile of the door separating the room in which was the discharge apparatus from the room in which was the photographic plate; also photographs of the shadows of the bones of the hand, of the shadow of a wire wound on a wooden spool, of a weight enclosed in a small box, of a compass in which the magnetic needle is completely surrounded by metal, of a piece of metal the lack of homogeneity of which was brought out by the X-rays, &c.

To show the rectilinear propagation of the X-rays there is a pin-hole photograph, which I was able to take by means of

the discharge-apparatus covered with black paper. The image is weak, but unmistakably correct.

15. I looked very carefully for interference phenomena with X-rays, but unfortunately, perhaps only on account of the small intensity of the rays, without success.

16. Researches to determine whether electrostatic forces affect X-rays in any way have been begun, but are not completed.

17. If we ask what X-rays, which certainly cannot be cathode rays, really are, we are led at first sight, owing to their powerful fluorescing and chemical properties, to think of ultra-violet light. But we immediately encounter serious objections. If X-rays be in reality ultra-violet light this light must possess the following characteristics:—

(a) It must show no perceptible refraction on passing from air into water, bisulphide of carbon, aluminium, rock-salt, glass, zinc, &c.

(b) It must not be regularly reflected to any appreciable extent from the above bodies.

(c) It must not be polarisable by the usual means.

(d) Its absorption must not be influenced by any of the properties of substances to the same extent as it is by their density.

In other words, we must assume that *these* ultra-violet rays behave in quite a different manner to any infra-red, visible, or ultra-violet rays hitherto known. I could not bring myself to this conclusion, and I have, therefore, sought another explanation.

There seems at least some connection between the new rays and light rays in the shadow pictures, and in the fluorescing and chemical activity of both kinds of rays. Now, it has been long known that besides the transverse light vibrations, longitudinal vibrations might take place in the ether, and according to the view of different physicists *must* take place. Certainly their existence has not up till now been made evident, and their properties have not on that account been experimentally investigated.

May not the new rays be due to longitudinal vibrations in the ether?

I must admit that I have put more and more faith in this idea in the course of my research, and it behoves me therefore to announce my suspicion, although I know well that this explanation requires further corroboration.

Würzburg. Physikal Institut der Universität,
December, 1895.



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